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INTERNATIONAL

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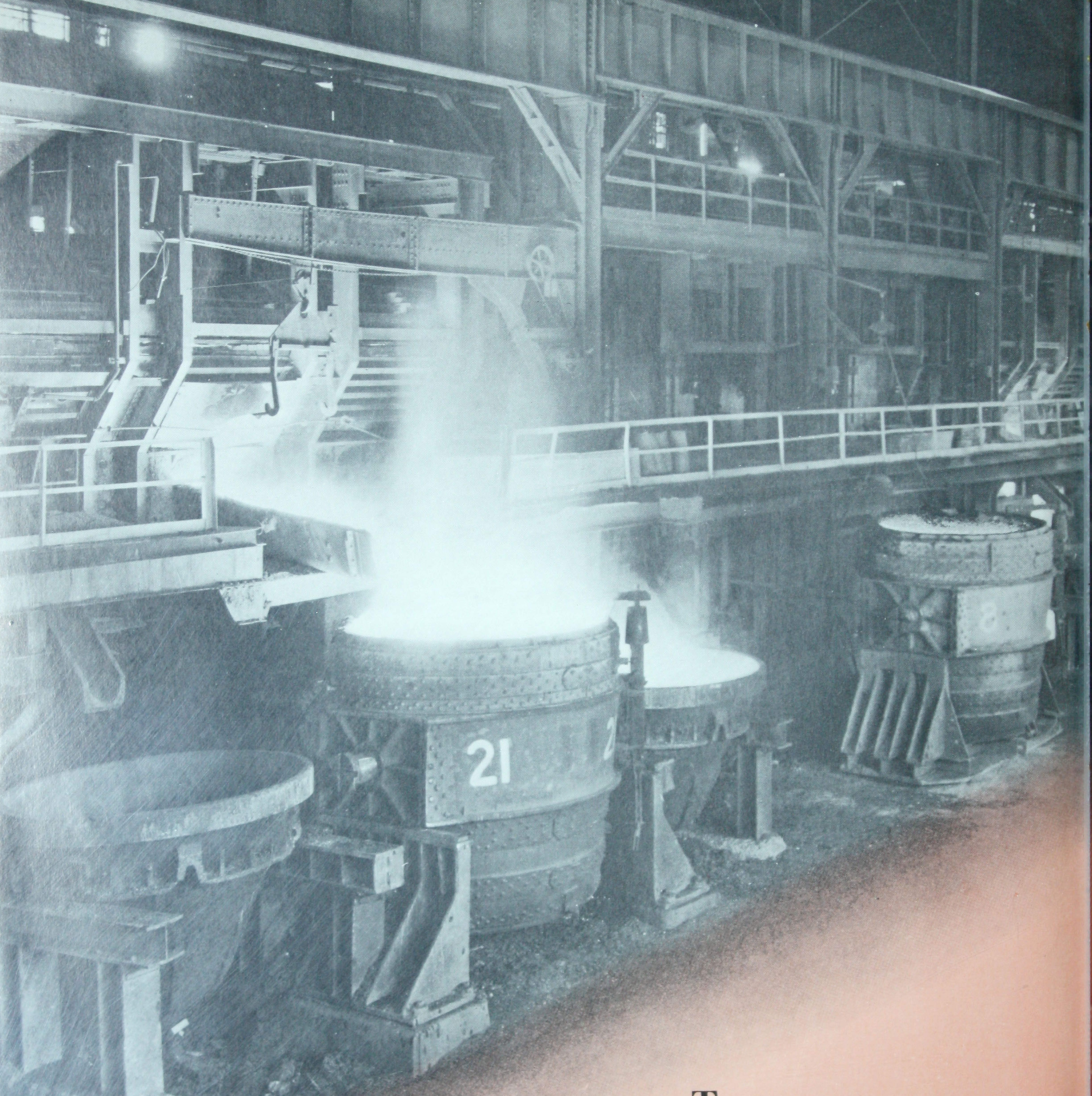
STEEL IN THE MAKING

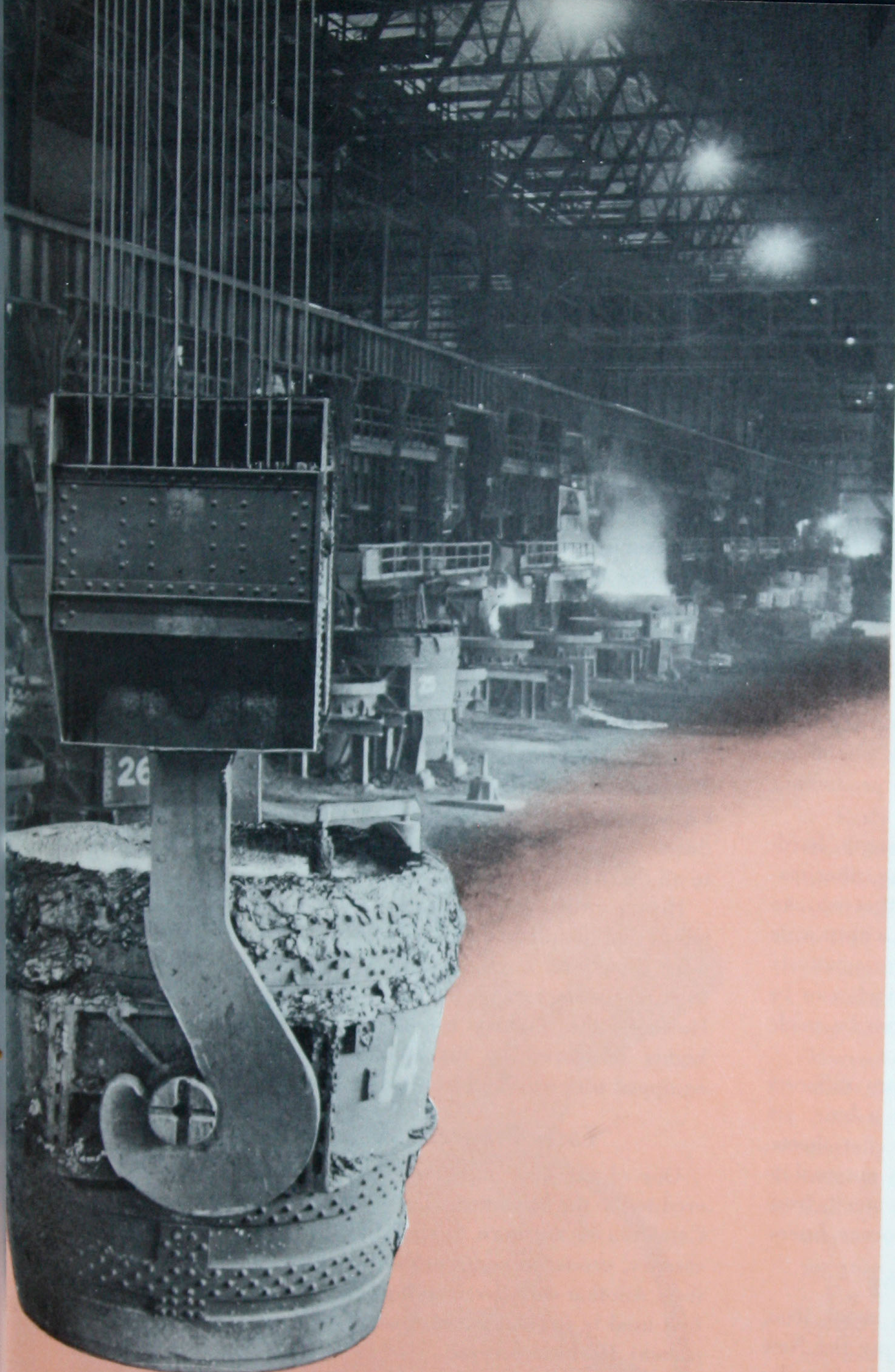


This is steel, newly-made, flowing in a molten stream from the open-hearth furnace.

We live in the Age of Steel. Every necessity and convenience of our daily lives — food, clothing, shelter, modern

FRONT COVER

Pouring newly-made steel from a huge ladle into ingot molds.



Open-hearth department of the Bethlehem Plant. Steel is being tapped into ladles simultaneously from three big furnaces.

STEEL IN THE MAKING

methods of transportation and communication — all depend in some way on this most useful of metals.

In this book we tell you how steel is made, and describe a few of the countless ways in which it serves us all.

The photographs of steelmaking facilities and processes appearing in this publication were taken in Bethlehem's steelmaking plants, which are located as follows:

BETHLEHEM, PA.
SPARROWS POINT, MD.
LACKAWANNA, N. Y.
STEELTON, PA.
JOHNSTOWN, PA.
SOUTH SAN FRANCISCO, CALIF.
LOS ANGELES, CALIF.
SEATTLE, WASH.

Steel...
our most useful metal

In the modern, highly industrialized era in which we are living, steel occupies a fundamental place. Today there is hardly any activity that does not depend on steel in some way, direct or indirect. Steel in its many forms is serving in countless ways to make our lives more enjoyable and more productive.

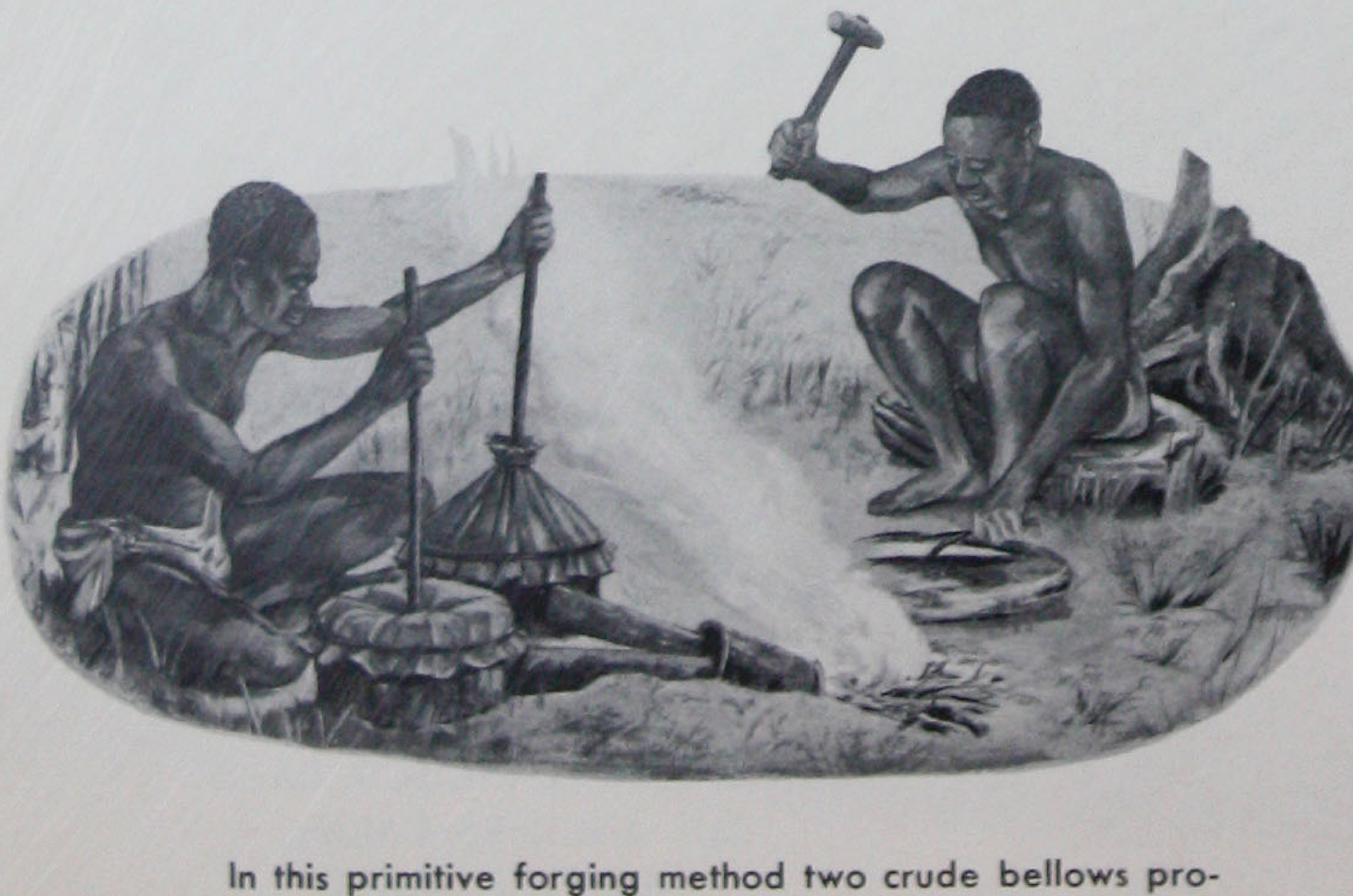
Of all metals steel is the most abundant and the least expensive—costing only about 4½ cents per pound on the average — due to the modern, efficient production equipment and methods of the steel industry.

Steel has a combination of properties—strength, hardness and toughness—that is unequalled by any other material. But even more important is the fact that we can accurately adjust and control these properties within wide limits. We can make steel exceptionally hard or relatively soft; that is why tools made from certain steels can be used to cut other steels. And special steels can be made to resist heat, wear, shock and corrosion.

Then, too, steel can be processed into so many different forms. It can be made into wire as fine as a hair, yet amazingly strong. It can be rolled into thin, flat sheets, then formed into the curving contours of an automobile fender. It can be forged into objects large or small, from hammer heads to propeller shafts for huge ocean liners.

The Beginnings of Ironmaking

The history of steel and that of its parent metal, iron, are closely interwoven. It was probably during the New Stone Age that primitive man learned to make iron by heating rocks and earth containing iron oxide in an open fire. Gradually he added improvements. He built stone hearths, used crude bellows to make hotter fires, and substituted charcoal for wood. Such simple furnaces provided man's supply of iron for many years.



In this primitive forging method two crude bellows produce a fire hot enough to make iron soft and workable.

The earliest writing to mention ironmaking is the Book of Genesis, where it is recorded that Tubal-Cain, seven generations after Adam, forged cutting instruments of iron. The oldest objects made of iron that are still in existence are the remains of iron beads found in an ancient Egyptian cemetery dating back to 4000 B. C. There is also evidence that the Egyptians used iron tools when they built the pyramids as early as 3100 B. C.

Ancient writings indicate that the Chinese made iron around 2200 B. C. Skilled artisans in India, Korea and Japan made and used iron and steel many centuries ago. From India came a fine grade of steel which the Syrians used in forging the famous swords of Damascus.

In the Middle East the Persians, Medes, Hittites and Phoenicians carried on a trade in iron long before the Christian era. It was probably the Phoenicians who introduced iron to Greece, Rome, Spain and France, and so to all the Western world.

Homer's writings, which date back to about 850 B. C., tell us that the prizes awarded winners of Olympic contests were sometimes made of iron. Iron was also made and used by the ancient people of Britain, France and Spain. However, the military use of ferrous metals was most highly developed by the Romans, whose legions were equipped with excellent iron and steel armor and weapons.

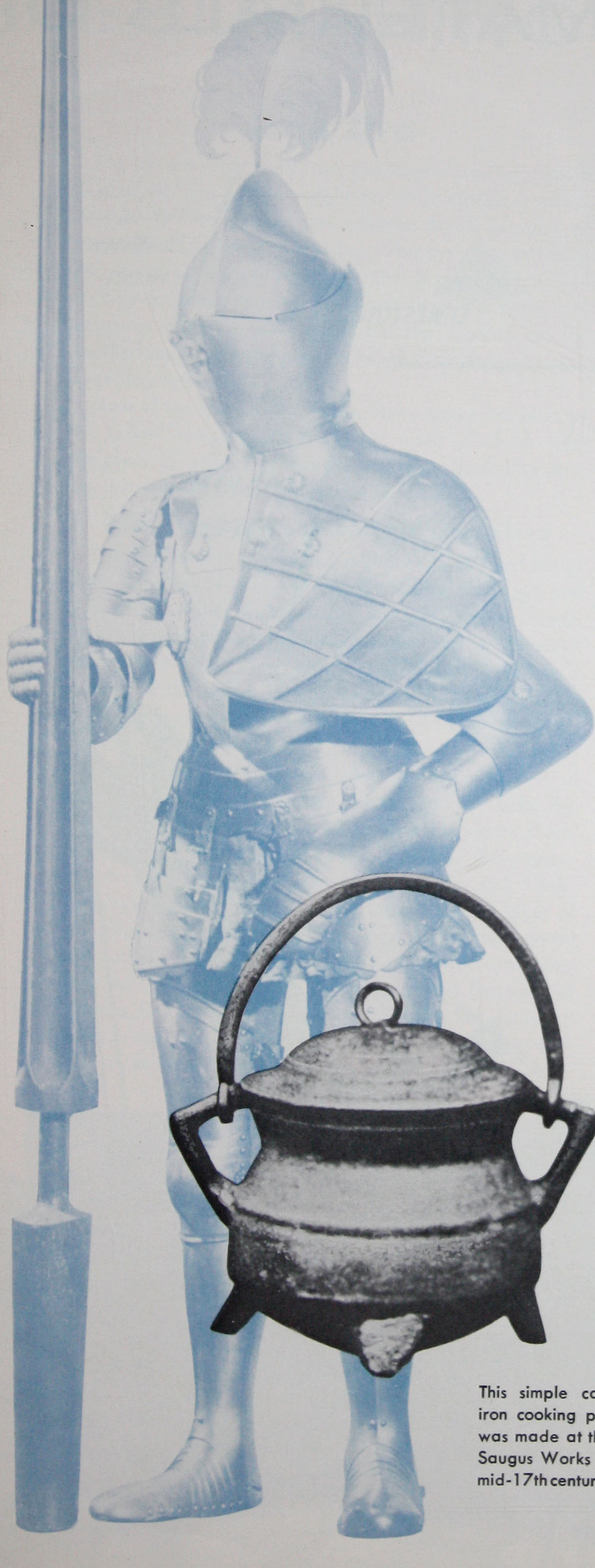
Early Progress in Ironmaking

One of the first important advances in ironmaking is credited to the Spaniards. The Catalan forge, developed in Catalonia in northern Spain, probably before the eighth century, produced considerable quantities of wrought bar iron. Another early ironmaking furnace was the *stuckofen*, first used in Germany and Austria, a crude version of the present day blast furnace.

As these and other furnaces made an increased supply of iron available during the late Middle Ages, European artisans became remarkably skillful in the art of forging iron and, sometimes, steel bars. They produced numerous metal tools, weapons, cooking utensils, locks and — their supreme achievement — richly ornamented suits of armor. Until the invention of gunpowder, the knight in armor remained practically invulnerable to the weapons of the day.

In earlier times steel was thought to be simply a superior grade of iron. By the seventeenth century, however, European ironmasters understood the basic difference between iron and steel — steel being a refined form of iron — and were producing steel in small quantities. One early use of this steel was the fine cutlery for which the town of Sheffield, England, is famous to the present day.

This skillfully made suit of steel armor is a striking example of the amazing ability of medieval smiths.



Early blast furnace near Pottstown, Pa., which operated for 134 years.

Steelmaking in America

Early in the seventeenth century the London Company built the first ironworks in the New World at Falling Creek in Virginia. But in March, 1622, just as operations were starting, Indians attacked the settlement, destroying the works and killing 347 colonists. The only survivor was young Maurice Berkeley, son of the leader.

Another Colonial ironworks—recently rebuilt according to its original design—was completed in Saugus, Massachusetts, in about 1650. One of the first iron articles made there, a simple cooking pot, is still in existence.

It was not until the latter half of the nineteenth century that any significant progress was made in producing steel in large quantities. Then two men, Sir Henry Bessemer, an English engineer, and William Kelly, an American ironmaster, independently developed the method of converting pig iron into steel now known by Bessemer's name.

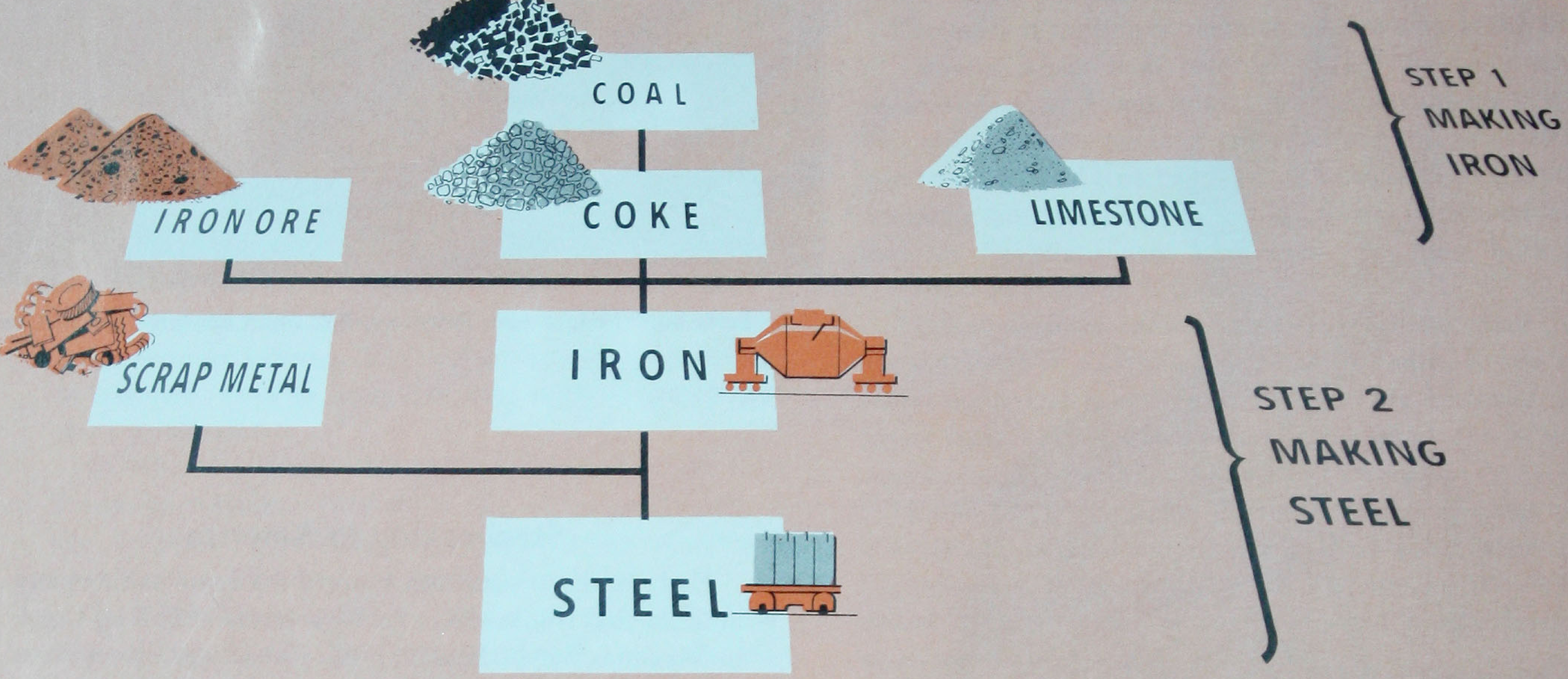
For some years nearly all the steel produced was made by the bessemer process. However, late in the nineteenth century the more efficient open-hearth process was developed. By 1909 more steel was being made in open-hearth furnaces than in bessemers. A later development was the introduction of the electric-furnace process.

The growth of the steel industry has been nothing short of phenomenal. In 1890 America's steel furnaces poured 5 million tons of steel; in 1917, 50 million tons; in 1953, nearly 112 million tons, about 43 percent of the entire world output. This tremendous increase in steel production has been closely interwoven with the industrial advances of the twentieth century that have given the people of the United States the highest standard of living the world has ever known.

Today, steel is the backbone of our economy — our greatest strength in peace and in war.

This simple cast iron cooking pot was made at the Saugus Works in mid-17th century.

THE RAW MATERIALS OF



Four basic raw materials—iron ore, coal, limestone and scrap metal—are used to make steel.

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The first step of steelmaking, the making of iron, requires iron ore, coal (after it has been converted into coke) and limestone.

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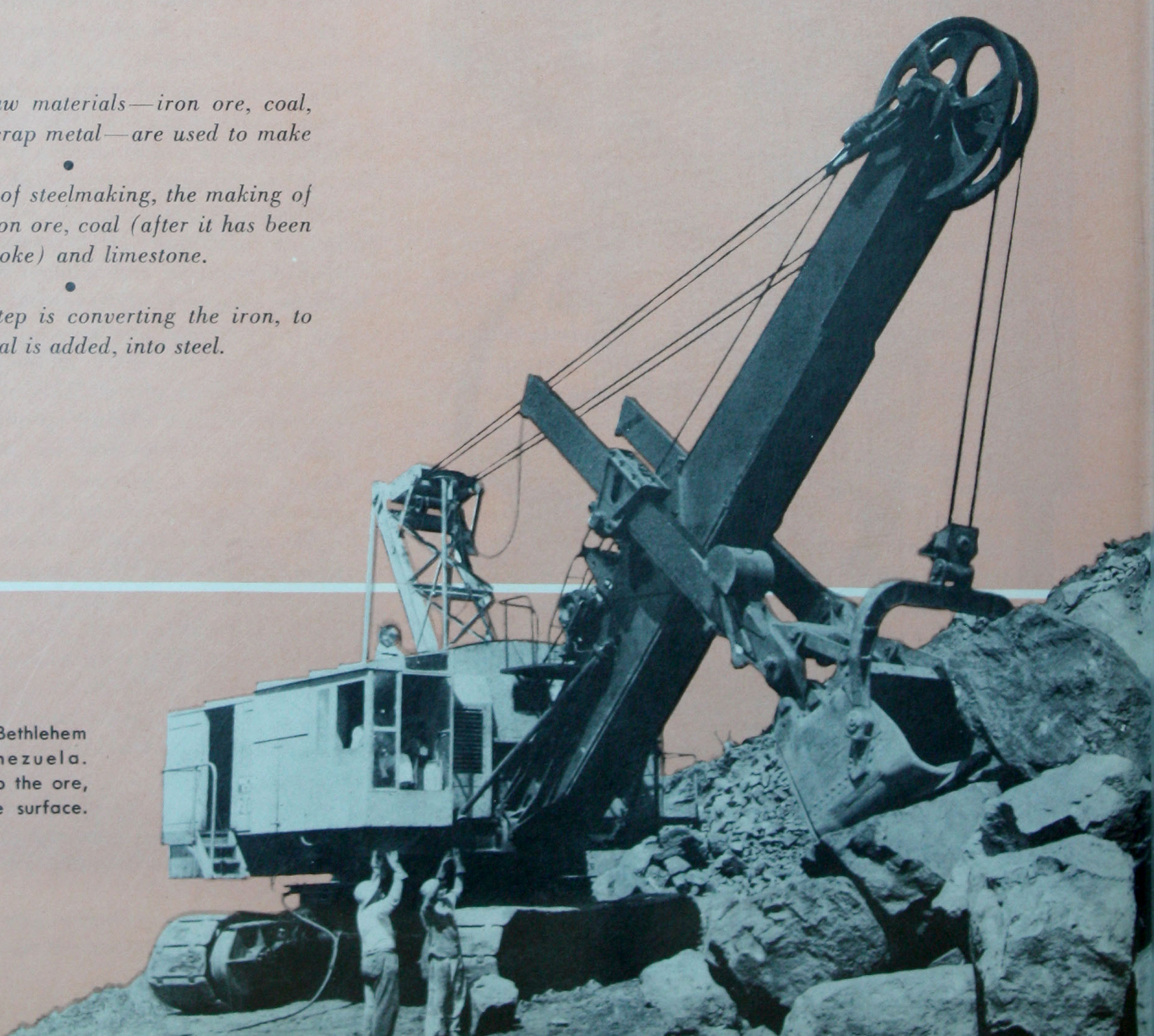
The second step is converting the iron, to which scrap metal is added, into steel.



Open-pit mining at Bethlehem mine at El Pao, Venezuela. Power shovels scoop up the ore, which lies close to the surface.

STEELMAKING

These ore unloaders are scooping iron ore from the hold of a vessel in 17-ton bites.

Iron Ore

The basic source of all iron and steel is *iron ore*, which consists of iron oxide combined with alumina, silica, phosphorus, manganese and sulphur. Small amounts of iron are found almost everywhere. But the areas in which iron ore is mined are relatively few. It costs so much to provide facilities to extract the ore from the earth and transport it to the steel mills that the expense can be justified only when the ore is of high grade and present in large deposits.

Most of the iron ore mined in this country has been of two types: *hematite* and *magnetite*, both of which average about 70 percent in iron content when pure. Hematite has a brick-red color. Magnetite is black.

Both Domestic and Foreign Ores Used

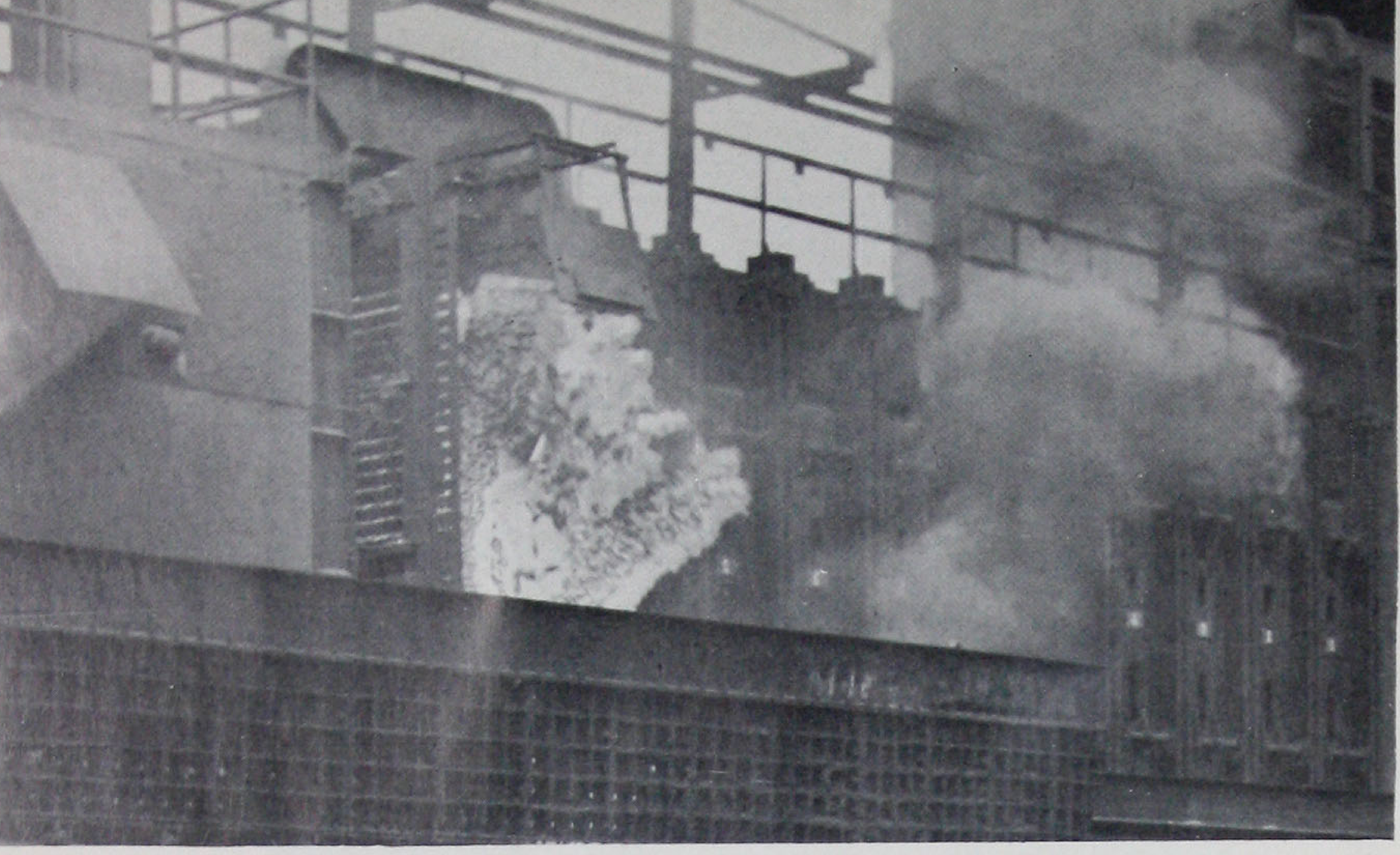
The leading iron-producing region in the United States is the Lake Superior district of Minnesota, Michigan and Wisconsin, which includes the famous Mesabi Range. Other important ore-producing areas are in Pennsylvania, New York, New Jersey and Alabama, and in a number of the Rocky Mountain states. Steel mills in the United States also import ore from Canada, South America, Europe and Africa.

Bethlehem Steel Company uses ore from several of these sources. Large tonnages come from the Lake Superior district, from the Cornwall Mine in eastern Pennsylvania, which dates back to the American Revolution, and from Bethlehem mines in Venezuela and Chile. Supplementing these sources, we import special types of ore from Sweden. Bethlehem is also developing several new sources of ore, including the Grace Mine near Morgantown, Pa.; a deposit at Marmora, in the Province of Ontario, Canada; and in Chile. In addition, this company plans to use ore from the large deposits in Labrador that are now being developed.

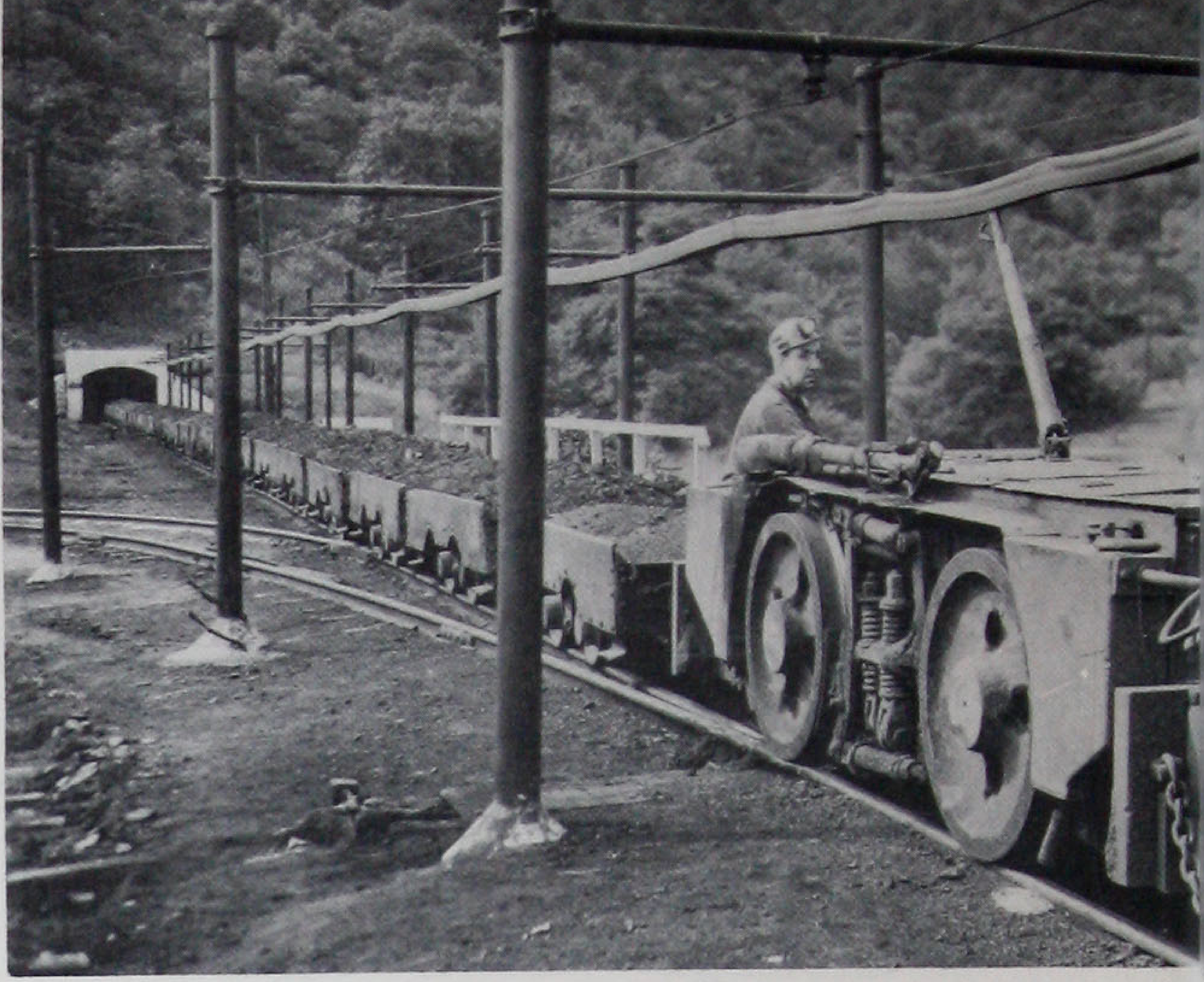
Taconite—A New Source of Iron

Another vitally important source of iron for the near future is *taconite*. This extremely hard rock, containing particles of iron oxide, is found in vast quantities surrounding high-grade ore deposits. However, taconite is too low in iron content in its natural state to be used in the iron-making blast furnaces. In order to solve this problem, several groups of steel companies have constructed pilot plants where they have developed a way to extract the iron oxide from taconite and concentrate it in marble-sized pellets with iron content of about 65 percent. One of the leaders in this research work has been Erie Mining Company, in which Bethlehem has a sizable interest. Erie is now building a full-scale plant where large quantities of taconite will be prepared for steelmaking.

A new source of iron ore is the Grace Mine, near Morgantown, Pa. Ore deposits, 1500 to 3000 feet underground, are reached by shafts and tunnels.



Discharging incandescent coke from oven. The coke is then quenched under sprays of water to prevent it from burning in the open air.



Coal mine at the Johnstown Plant, only steel plant in the U. S. located directly above large deposits of coking coal.

Coal

Coal is another of the basic raw materials of steelmaking. It is used to make *coke* which, in turn, is used as fuel in the blast furnaces where iron is made. Coking coal, a special type of bituminous or "soft" coal, is mined principally in western Pennsylvania, West Virginia—Bethlehem has mines in both these states—and in Illinois and Alabama.

Machinery has taken the place of pick-and-shovel work in many modern bituminous coal mines. Mechanical cutters slice into the solid blocks of coal, which are then blasted loose by explosives. Mechanical loaders gather up the coal and load it onto cars which carry it to the surface. Recently machines have been introduced that mine and load the coal in one operation, thus eliminating the need for blasting. Finally, the coal is mechanically crushed, sorted, washed and blended, in preparation for use in the coke ovens.

Coal is "Baked" in Coke Ovens

Coke ovens, which are located at the steel plant, are large rectangular ovens, usually arranged side by side in batteries of 40 or more. The newest ovens are approximately 40 feet long, about 13 feet high, and between 1 and 2 feet wide.

Crushed coal is dumped into the oven through openings in the top. The oven is closed, heated to about 2000 degrees F and kept at this temperature for 19 or 20 hours, while the intense heat is driving off the various gases in the coal. The solid matter which remains is pushed from the oven while glowing with heat and is quenched under sprays of water. The result is coke, a firm, porous, gray substance, about 85 percent carbon.

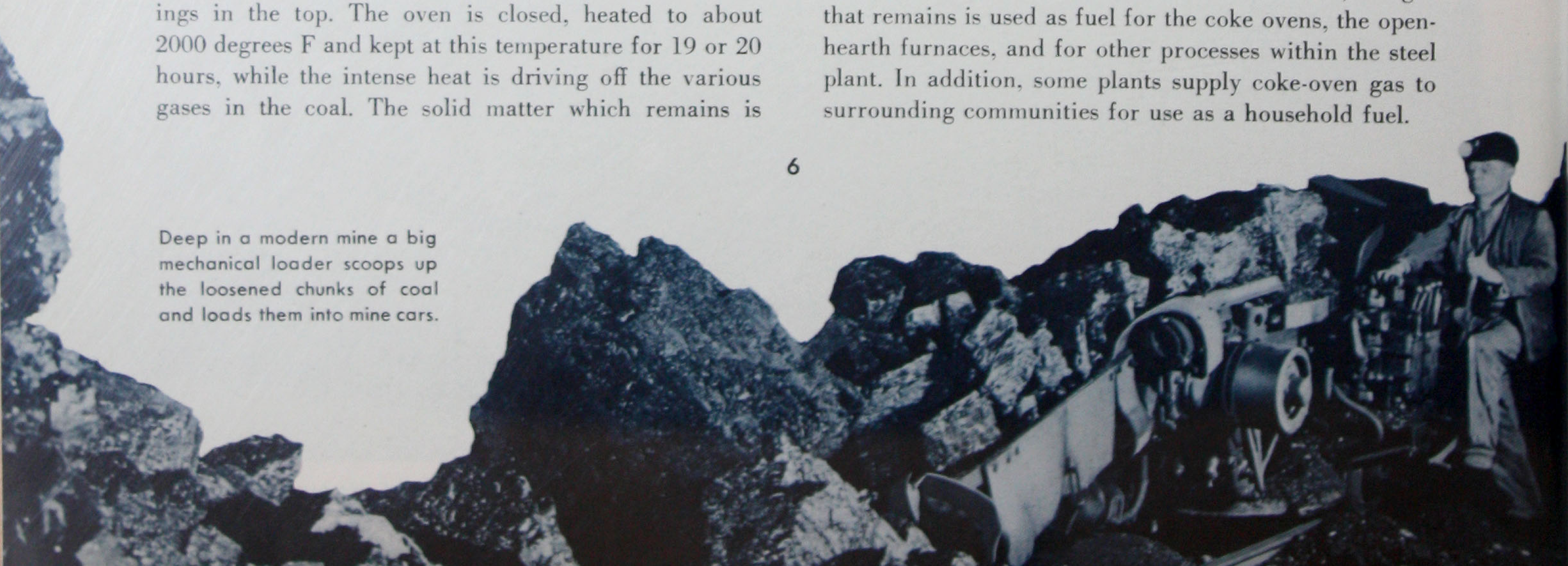
Coke is the ideal fuel for the blast furnaces. It burns rapidly with intense heat and supplies the carbon needed to make carbon-monoxide gas which plays a vital part in the blast-furnace process. Furthermore, coke has a strong enough structure to support the tremendous weight of the iron ore and limestone which are charged into the blast furnace.

Coking Process Yields Valuable Gas

For every ton of coke, an oven produces 16,000 to 18,000 cubic feet of *coke-oven gas*. This gas is extremely important both as a source of byproduct chemicals and as a fuel for use within the steel plant.

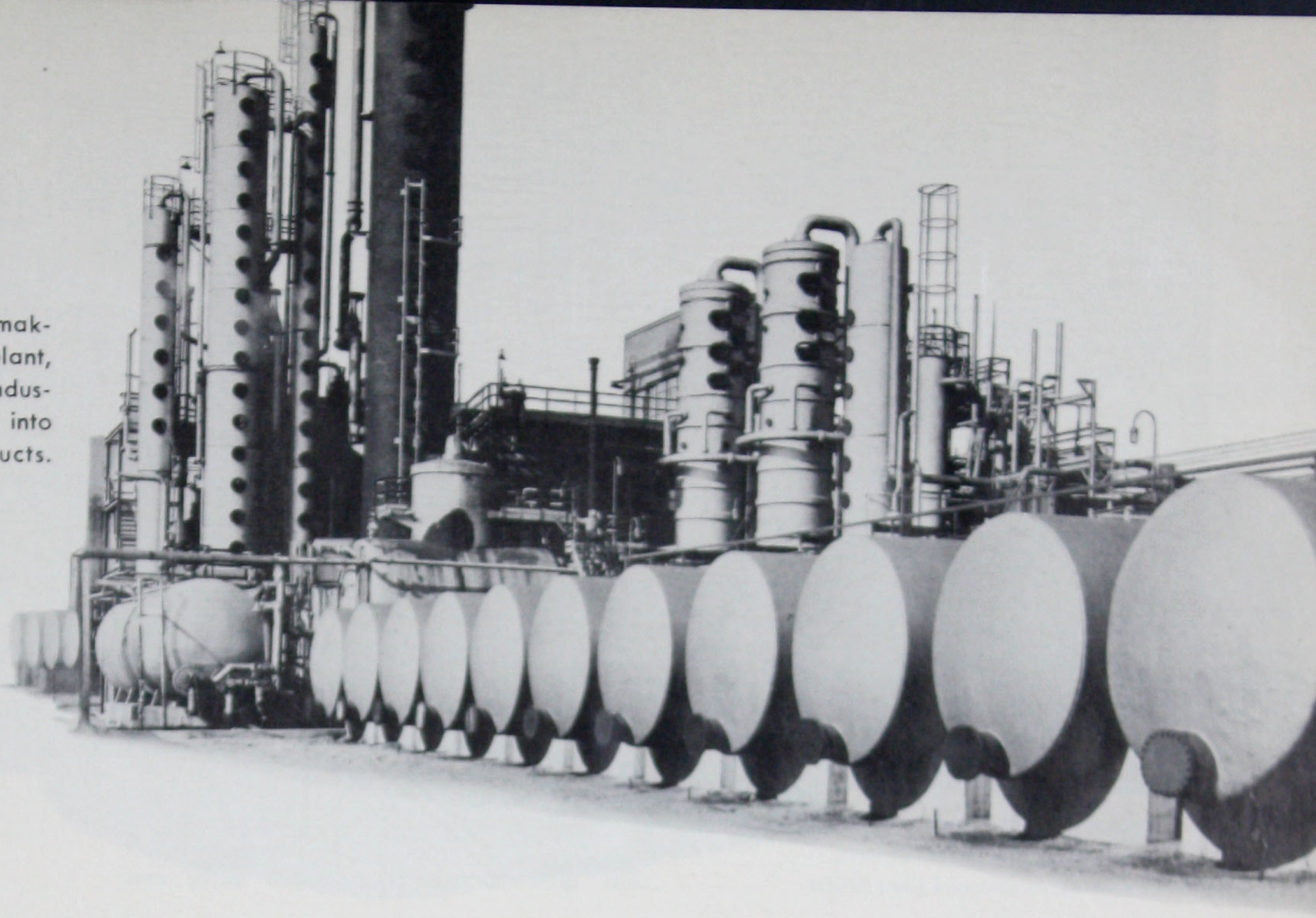
The gas passes from the ovens into a system which recovers the primary byproducts such as tar, ammonium sulphate, naphthalene, pyridine and light oils. These basic chemicals are further processed to yield tar-acid oils, benzol, toluol, xylol, etc. Other industries use these chemicals to make nylon, synthetic rubber, aspirin, TNT, moth balls, perfumes, dyes, sulpha drugs, plastics and thousands of other well-known products.

After the coal chemicals have been extracted, the gas that remains is used as fuel for the coke ovens, the open-hearth furnaces, and for other processes within the steel plant. In addition, some plants supply coke-oven gas to surrounding communities for use as a household fuel.



Deep in a modern mine a big mechanical loader scoops up the loosened chunks of coal and loads them into mine cars.

Byproducts of coke-making, processed in this plant, are sold to chemical industries for conversion into many familiar products.



Limestone

Limestone, a gray rock consisting mainly of calcium carbonate, is used in blast furnaces and, to a smaller extent, in the open-hearth furnaces. Limestone acts as a cleanser or *flux*, soaking up the impurities and forming a scum-like *slag*. Limestone for use in steelmaking comes from Bethlehem quarries. There it is cleaned and crushed in preparation for use in the furnaces.

Scrap

One of the most important sources of new steel is old steel and iron. No matter how old and rusty the metal may become, it can always be melted down and converted into new steel. In fact, steel plants that do not have blast furnaces often make steel entirely from ferrous scrap. But under ordinary steelmaking conditions about one-half of the iron content of steel comes from molten pig iron and the remainder from scrap.

Broadly speaking, two kinds of scrap are used in steelmaking. "Home" scrap comes from within the steel plant itself. For every ton of steel produced, only about three-quarters of a ton is actually shipped out. The remaining quarter-ton, which is discarded during processing, is returned to the steelmaking furnaces.

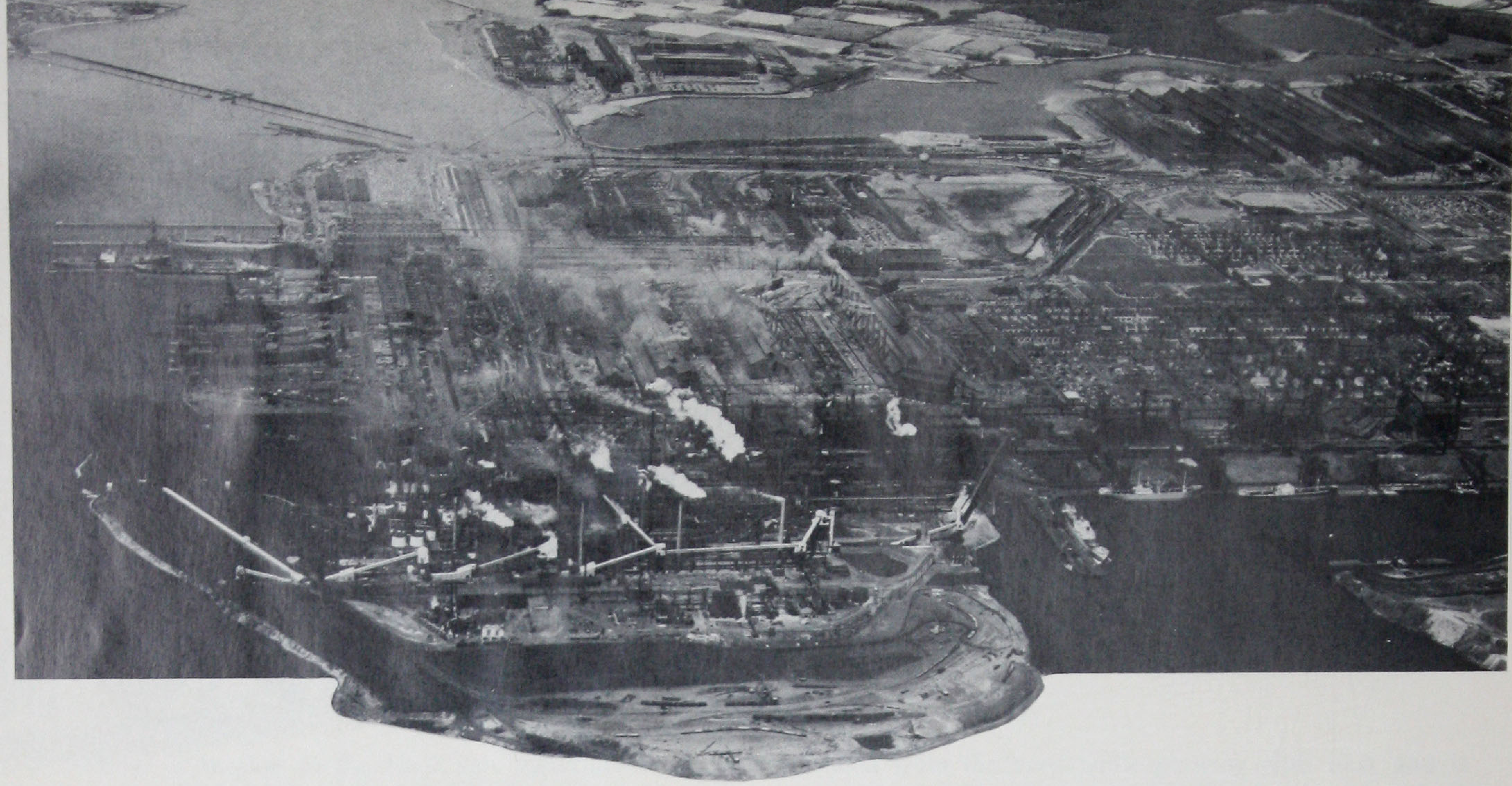
"Outside" scrap is usually purchased from scrap dealers who collect steel or iron in any form that is not otherwise useful, or that has outlived its usefulness. The chief sources of scrap are worn-out or obsolete equipment and parts, such as dismantled machinery, locomotives and ships, and old railway cars and rails. Another source is the chips and shavings that accumulate in machine shops and other places where metalworking is done.

An Example of the "Rebirth" of Steel

During the years right after World War II most railroads retired many steam locomotives and replaced them with diesels. The old locomotives provided thousands of tons of scrap, much of which was converted into steel frames, engines and other parts of the new diesels.

This quarry near Bridgeport, Pa., supplies limestone for steelmaking.

Retired locomotives provide scrap for conversion into new steel.



The Sparrows Point Plant, near Baltimore, second largest steel plant in the world, and largest on the Eastern Seaboard. Sparrows Point, with annual steelmaking capacity of approximately 6,000,000 tons, has a normal payroll force of 25,000 employees, and an annual payroll of over $100,000,000. More than 15,000 electric motors supply 600,000 horsepower for use in the plant. Every day the plant consumes about 550 million gallons of water, more than is used in the nearby city of Baltimore, sixth largest city in the United States.

Water

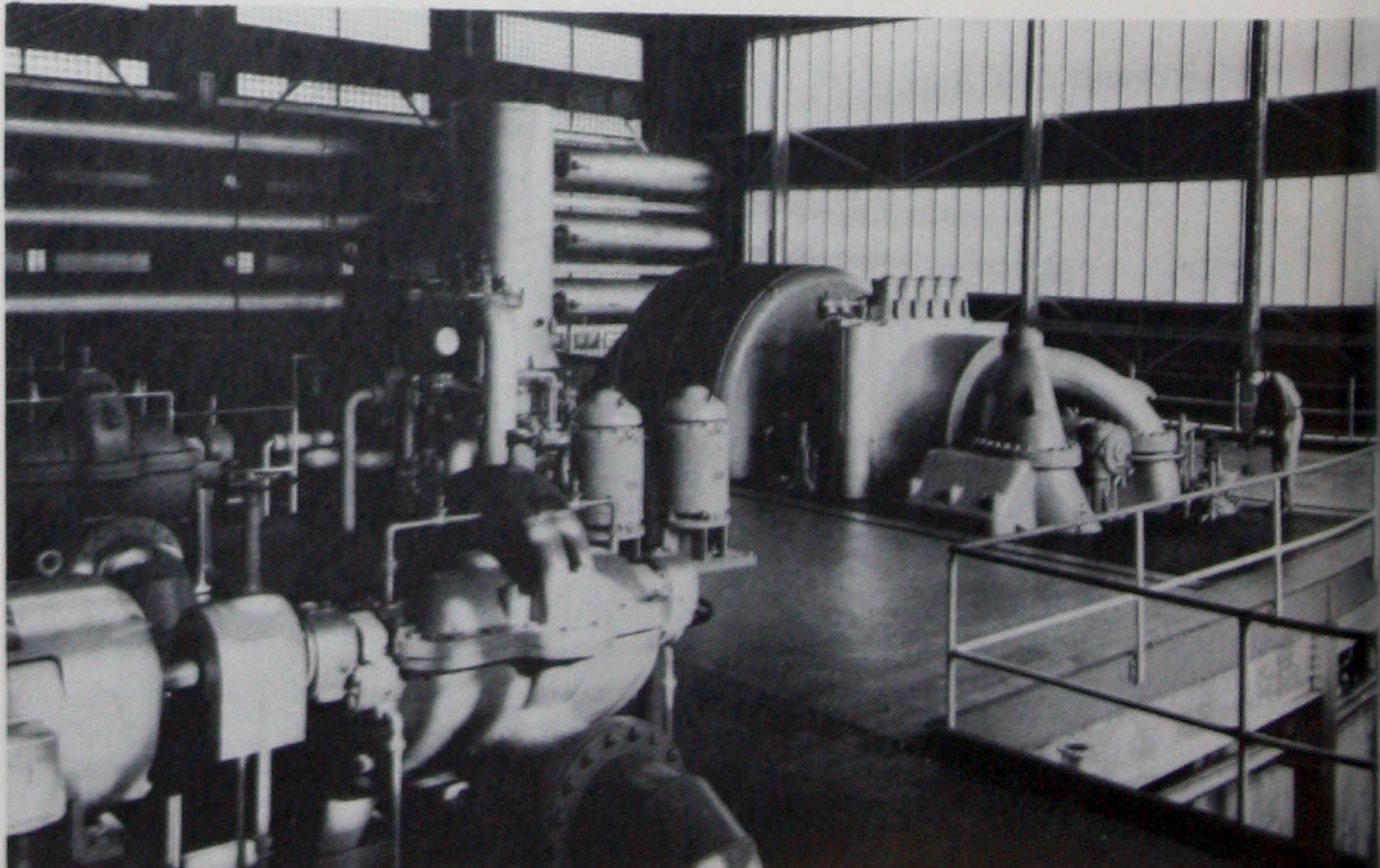
Steelmaking takes tremendous amounts of water—20,000 to 25,000 gallons of water for each ton of steel produced. Steel plants use water for cooling equipment and structures such as blast furnaces and open hearths. It is also used for the generation of steam, for the cleaning and cooling of blast-furnace and coke-oven gases, and for cooling steel during processing.

Air

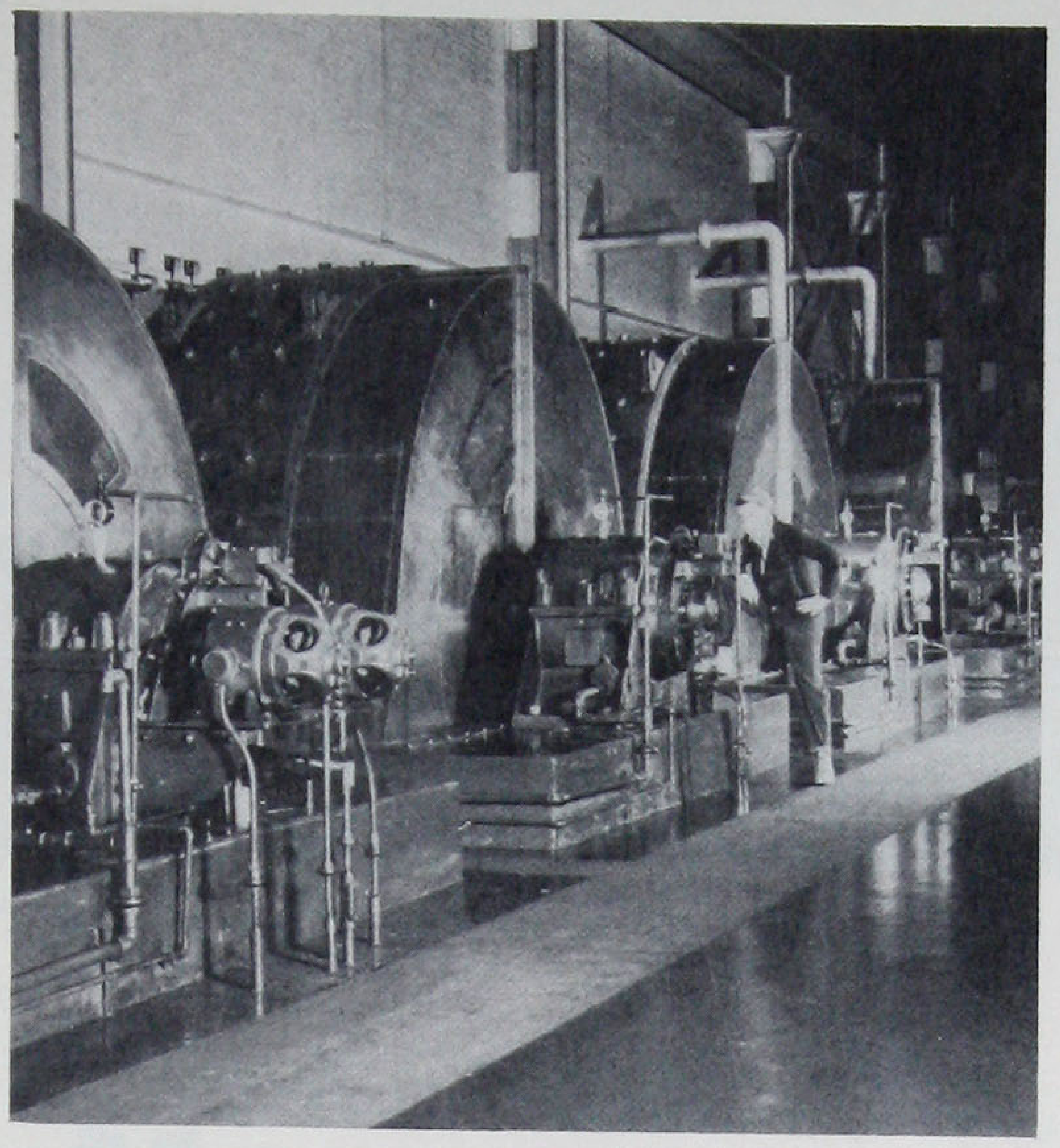
It is an amazing fact that the air used in steelmaking actually outweighs the solid raw materials. Oxygen in the air permits the fuels used in steelmaking to burn, and assists in the various chemical reactions. From 4 to 4½ tons of air must be supplied to a blast furnace in order to make 1 ton of pig iron. Another ton or so of air is needed in converting the iron into steel.

The 11-billion-gallon reservoir on Quemahoning Creek, one of four needed to supply the Johnstown Plant with 140,000,000 gallons of water per day.

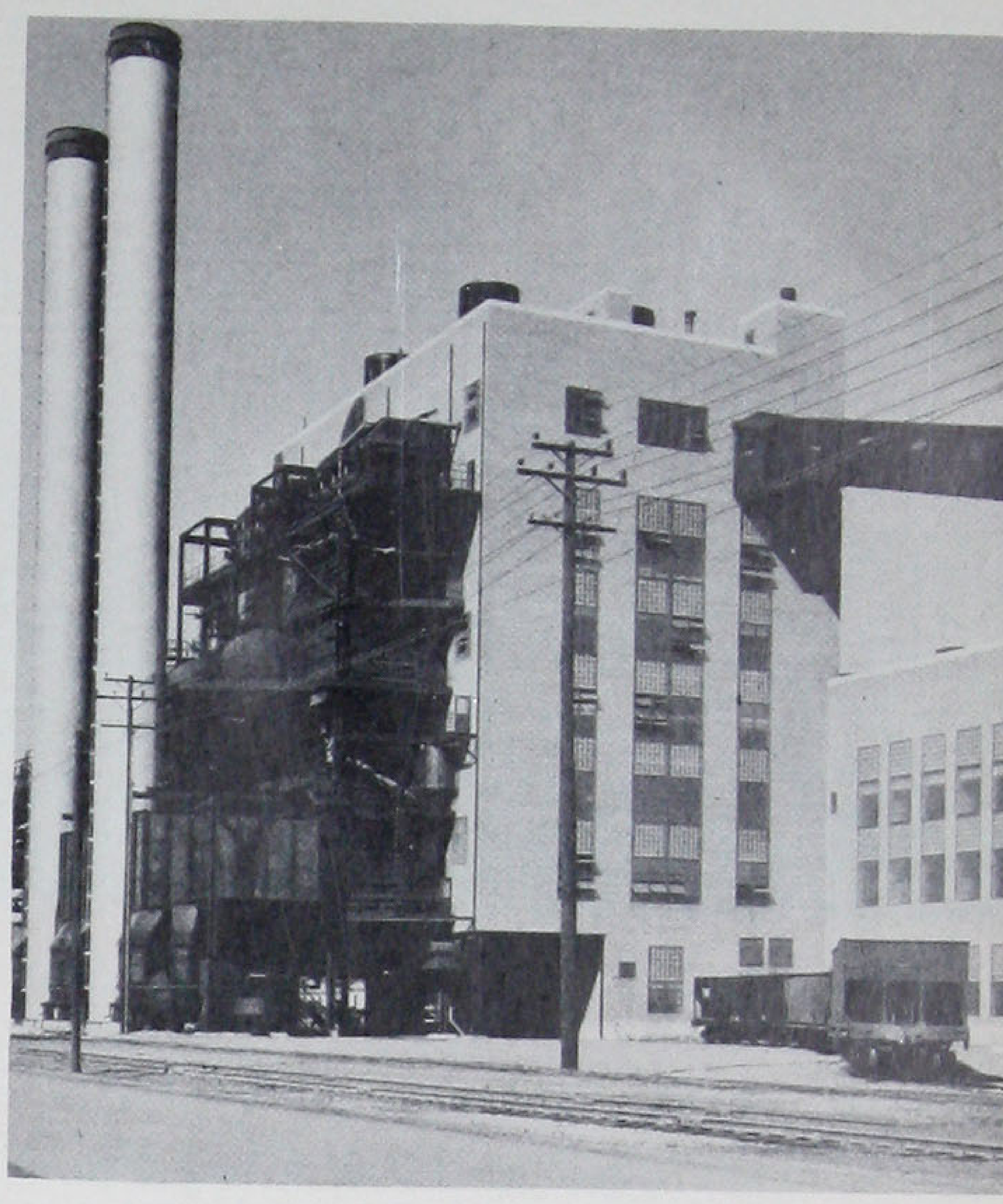
This 11,150-horsepower turbo-blower supplies air for the Steelton Plant's big blast furnaces. It takes about 5 tons of air to make 1 ton of steel.



Workmen rebuilding open-hearth furnace with refractory bricks. Such maintenance work is a never-ending job in a large steel plant.



Electricity supplies most of the power used in steelmaking. These massive electric motors drive the rolls in a sheet-strip mill.



Electric power for Sparrows Point is generated in this huge steam plant which uses blast-furnace gas for fuel.

Human Skills

If you visited a steel plant, you might be so impressed by the size and complexity of the furnaces and mills that you would overlook the all-important human element in steelmaking. It takes people—many different kinds of skill—to make steel.

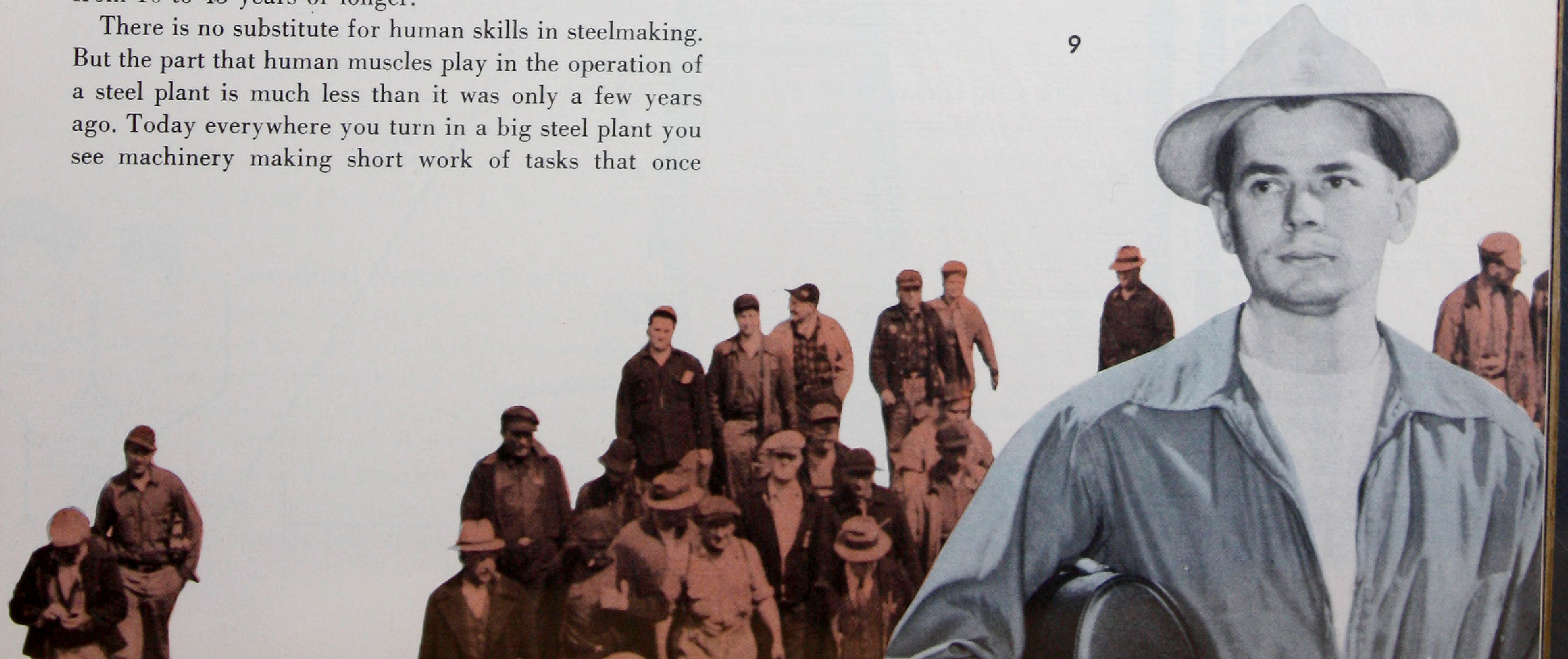
Our Sparrows Point Plant, for example, has a normal payroll force of 25,000 employees. Of these, 6,000, or about one out of every four, are engaged in maintenance, service and transportation work alone. They include carpenters, electricians, machinists, bricklayers, painters, truck drivers, firemen and plant patrolmen. The 19,000 employees directly engaged in the production of steel include hundreds of other specialized skills. These skills are based on years of experience. Almost one-half of all Bethlehem employees have been with the company for from 10 to 45 years or longer.

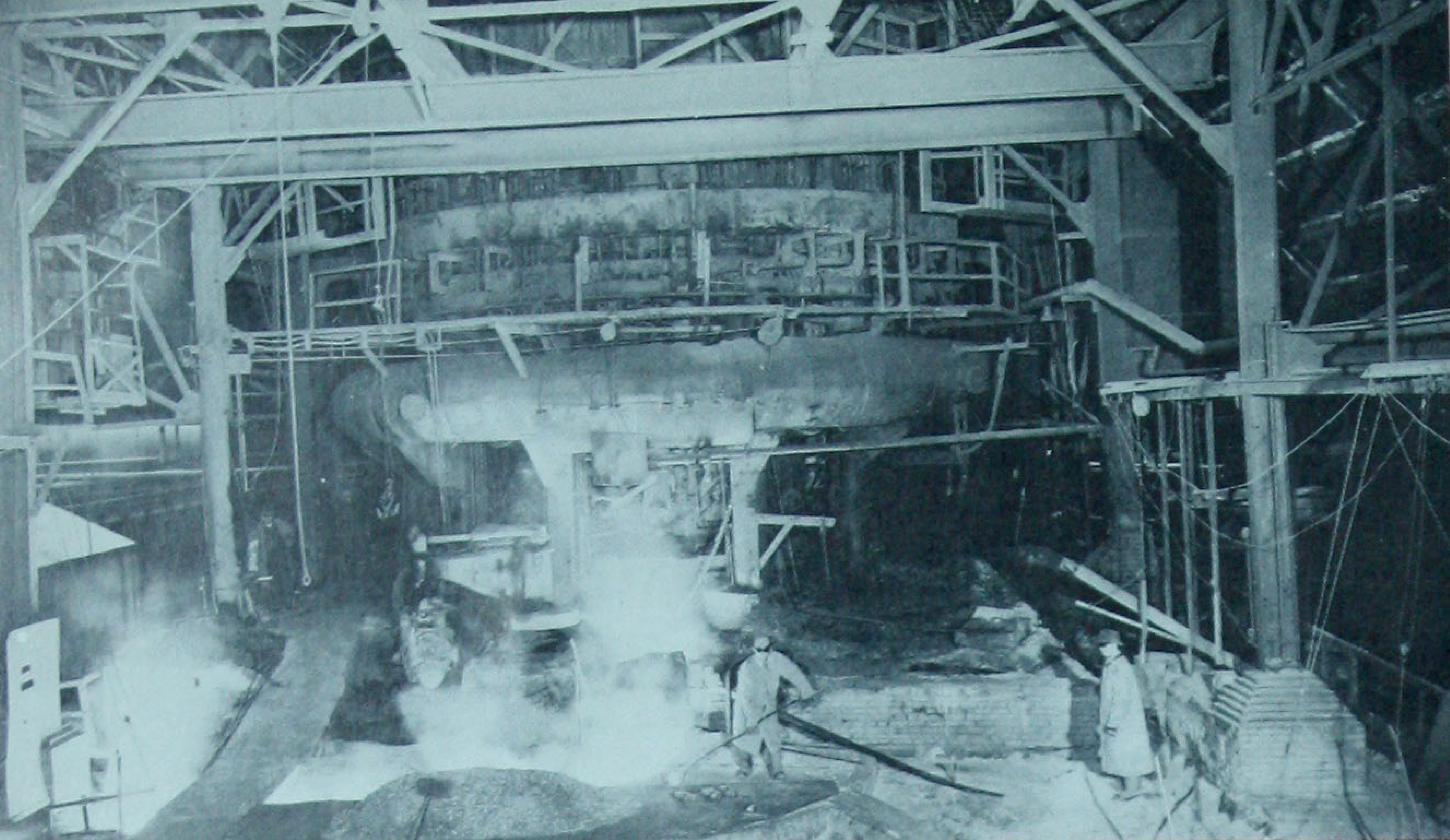
There is no substitute for human skills in steelmaking. But the part that human muscles play in the operation of a steel plant is much less than it was only a few years ago. Today everywhere you turn in a big steel plant you see machinery making short work of tasks that once meant hard labor. This mechanization in steelmaking does more than save human drudgery. It increases efficiency, thus producing more steel at lower cost.

Electric Power in Steelmaking

Here are a few figures that give an indication to what extent mechanized equipment is used in steelmaking.

The power needed to produce 1 ton of steel — to operate the furnaces, rolling mills and many other facilities within the plant — amounts to about 700 horsepower-hours. A large steel mill such as our Lackawanna Plant requires electrical installations as large as those of a city of 100,000 population. The 12,000 or so electric motors in the Lackawanna Plant deliver over 500,000 horsepower.



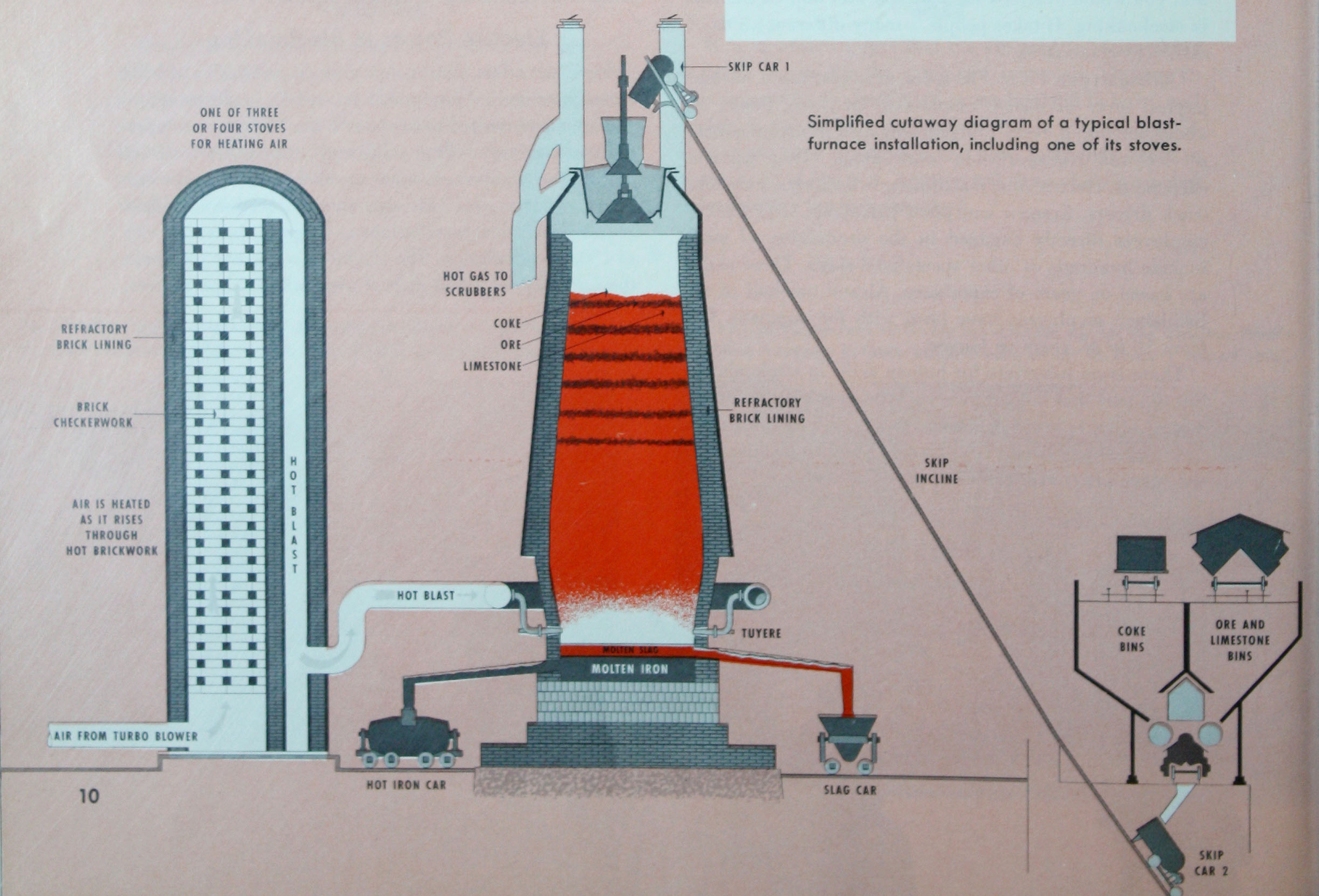


Tapping a blast furnace. Molten pig iron runs down a trough to the left. The workman at center is taking a sample for analysis.

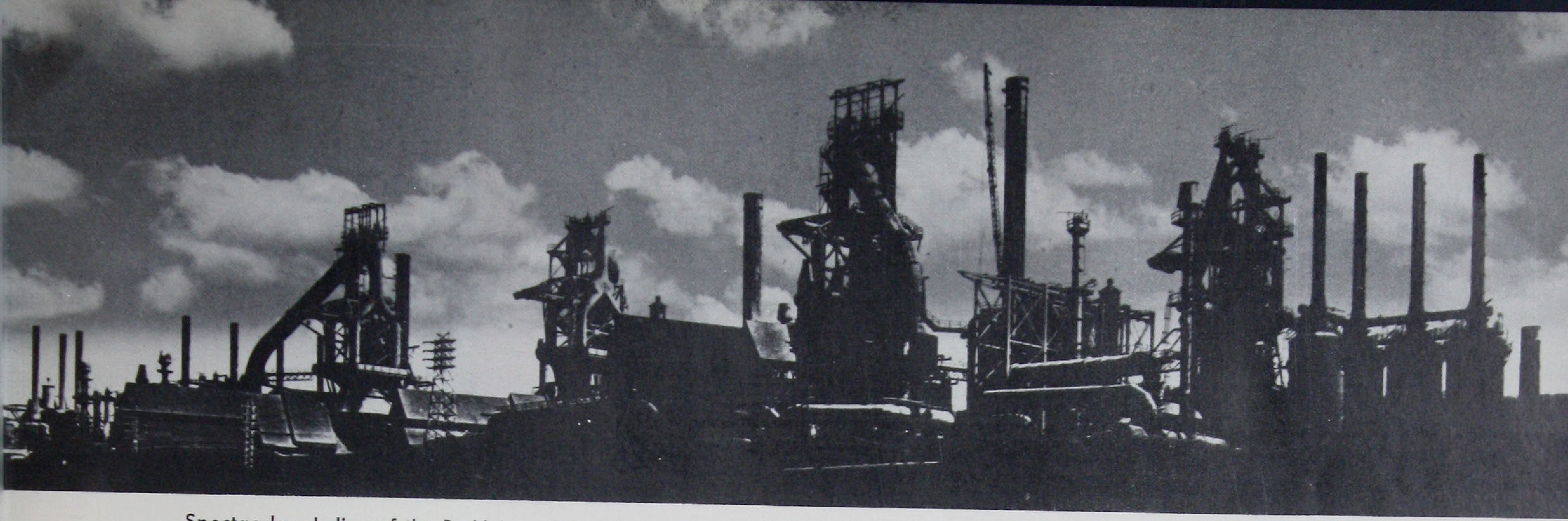
Making Iron in the Blast Furnace

Iron ore is converted into pig iron by means of a series of chemical reactions that take place in the blast furnace.

- *First — heated by a hot blast of air from the stoves, the coke burns, creating gases.*
- *Second — these gases react with iron oxides in the ore, removing the oxygen and leaving metallic iron.*
- *Third — the limestone creates a slag which absorbs much of the silica and other impurities from the ore.*



Simplified cutaway diagram of a typical blast-furnace installation, including one of its stoves.



Spectacular skyline of the Bethlehem Plant along the Lehigh River. The blast furnaces tower over other steel-plant structures.

A blast furnace, together with its stoves and other equipment, makes a huge and complicated structure. But its basic design is quite simple. As shown in the diagram, the blast furnace is essentially a tall, brick-lined steel shell, approximately cylindrical in shape. The typical blast furnace is well over 100 feet in height, with a hearth diameter of 25 feet or more, and a daily output of between 800 and 1700 tons of iron. For example, Furnace "D" at our Bethlehem Plant is 237 feet high with a hearth about 29 feet in diameter. It can produce 1600 tons of iron daily.

Skip cars, running up and down an inclined track, carry the *charge* — iron ore, coke and limestone — from bins in the stock house to the top of the blast furnace where they are dumped into the furnace through a hopper.

The very large pipes that are an important part of the blast furnace bring preheated air to the furnace and carry away the gases that are produced.

Preheating Air for Blast Furnace

Three or four tall cylindrical structures, sometimes over 100 feet high, stand close to the blast furnace. These are the *stoves* that heat the air before it is blown into the furnace. They contain thousands of heat-resisting bricks arranged in a checkerboard pattern which permits gas and air to pass through. First, gas from the blast furnace is burned in one of the stoves, heating the bricks in its interior. Then the gas is diverted to another stove and the air being blown into the furnace is routed through the first stove. As the air rushes through the hot brickwork it absorbs heat stored in the bricks, which raises its temperature to about 1000 degrees F, hot enough for use in the blast furnace.

How the Blast Furnace Works

The raw materials are charged into the furnace in alternate layers of iron ore, coke and limestone. The hot air from the stoves is blown into the furnace through *tuyeres* near its base. The oxygen in the air reacts with the carbon in the coke, forming carbon-monoxide gas and creating intense heat. The gas rises through the charge, combining with the oxygen in the iron oxides and reducing the ore to metallic iron at a temperature of about 3000 degrees F. The molten iron trickles down through the charge and collects in a pool on the hearth.

At the same time, the intense heat converts the limestone into lime, which combines with most of the silica and other impurities from the iron ore and coke, forming molten slag. This slag drips down to the hearth where it floats on top of the heavier iron.

The iron is tapped every five or six hours; the slag is removed more frequently. These *casts* of iron average from 150 to 350 tons, according to the size of the furnace. The molten iron is taken to the steelmaking department of the plant where it is kept hot in an enclosed container called a *hot-metal mixer*. It is later converted into steel by either the open-hearth or bessemer processes.

Blast furnaces operate continuously, day and night, except when they are shut down for repairs, or for relining, which is normally required every four or five years.

Uses of Blast-Furnace Slag and Gas

For every ton of iron, the blast furnace produces about half a ton of slag and six tons of gas. After this gas has been cleaned, some of it is used in the stoves. The remainder serves as fuel for other processes in the plant.

The slag, poured into pots mounted on cars, is hauled away to the slag dump. Large quantities of slag are sold for use as aggregate in concrete. Some is processed into rock wool, commonly used to insulate homes.

Characteristics and Uses of Pig Iron

Iron from the blast furnace may contain about four percent carbon, one percent or less silicon, one and one-half percent manganese, and much smaller percentages of phosphorus and sulphur. It is hard and brittle, lacking the great strength, ductility and resistance to shock that steel possesses. Articles made of iron (then called *cast iron* because they are shaped by pouring, or "casting" molten pig iron into molds) are rigid and have great compressive strength, so that they will support a very heavy weight; but they generally are brittle, and shatter readily under blows. However, cast iron has many uses, such as for automobile-engine blocks, and for a wide variety of machinery parts. But most pig iron by far is used to make steel, as described on the following pages.

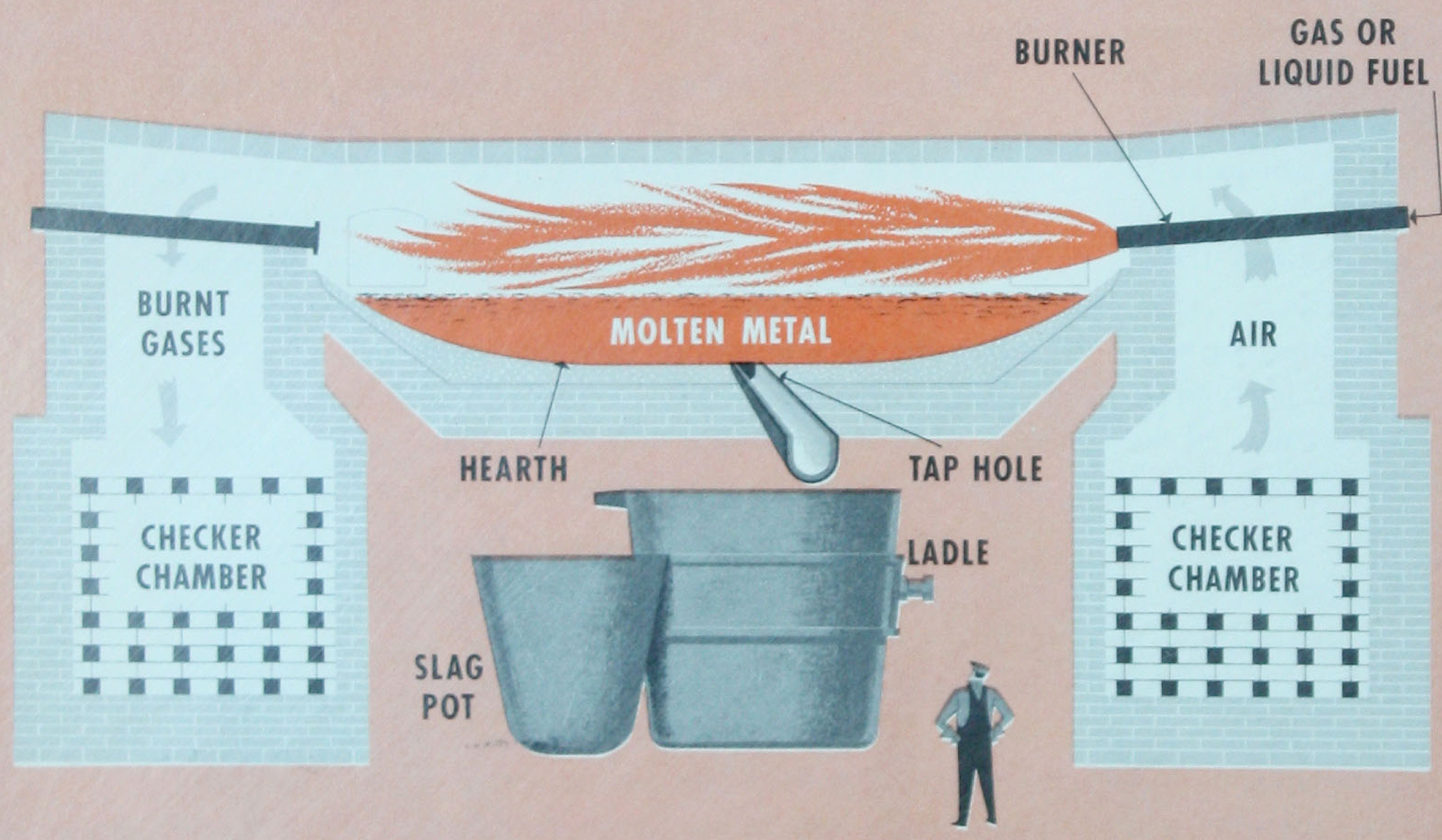
Steel is refined pig iron. The refining process further reduces the amount of impurities present in the metal. Technically speaking, steel is essentially iron combined with carbon, the carbon content ranging from a few hundredths of 1 percent up to about 1.40 percent. All steel also contains some manganese, silicon, phosphorus and sulphur.

Over 90 percent of all steel made is classified as **carbon steel,** *meaning that it contains a regulated amount of carbon and only slight traces of other elements. Most of the steel used in buildings, bridges, and other structures; in common tools such as hammers, screwdrivers and saws; in bolts and nuts, nails, farm fencing, and thousands of everyday articles, is plain carbon steel.*

The remaining 10 percent or so consists of **alloy steels.** *An alloy steel is steel to which have been added carefully determined amounts of alloying elements such as manganese, nickel, chromium, vanadium, molybdenum, etc. These alloying elements impart certain highly desirable properties to the steel, such as exceptional strength and ability to withstand very high or very low temperatures.*

The refining process by which the excess carbon and impurities in the pig iron are eliminated, converting the iron into steel, may be carried out in either the open hearth or the bessemer converter. The methods of steelmaking are described on the following pages.

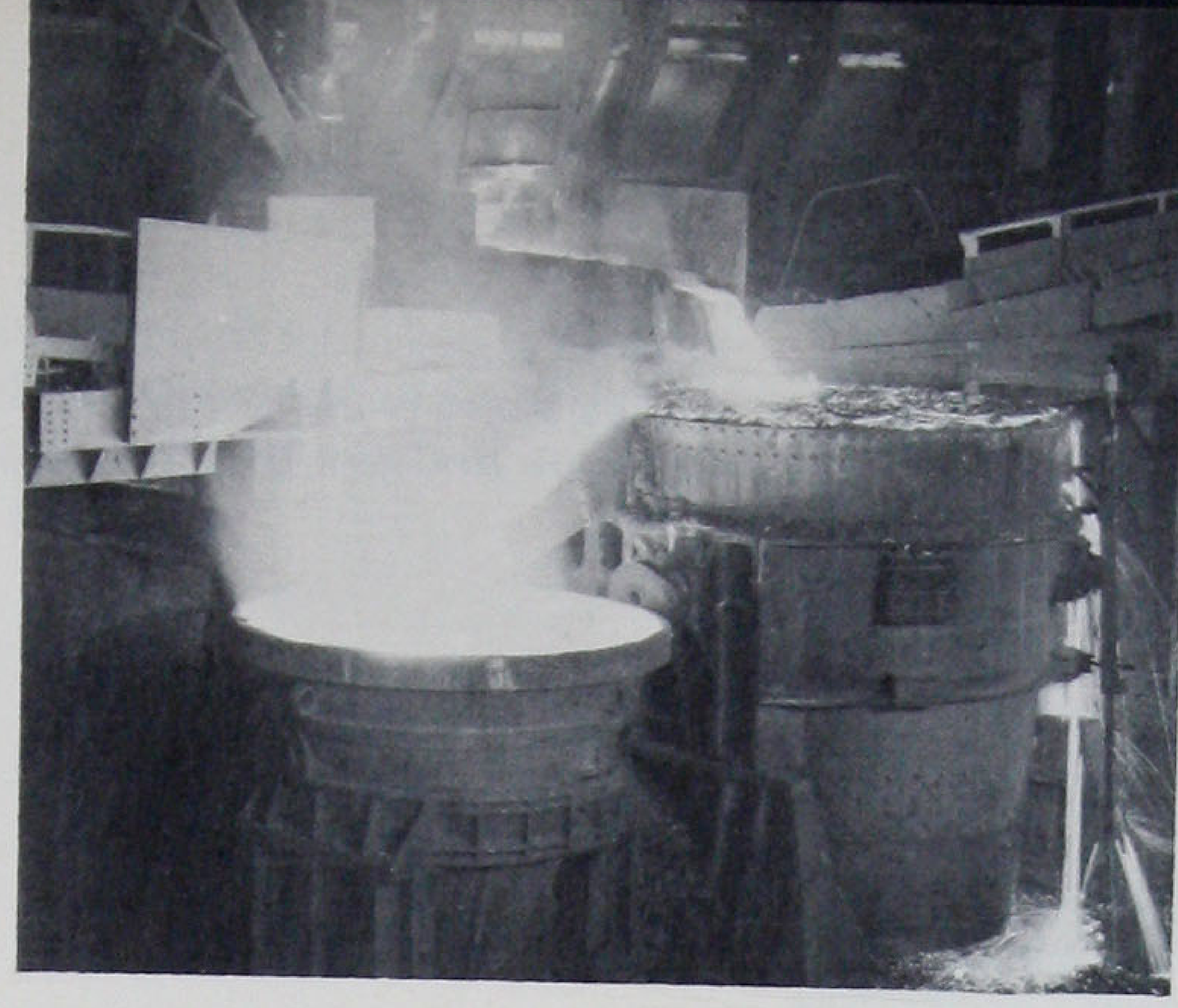
Making Steel



Simplified cutaway diagram of a typical open-hearth furnace, viewed from the tapping side.

Open-hearth charging floor at the Saucon Division of the Bethlehem Plant, where steel is made for rolling into structural shapes.

Taking a sample of slag from open hearth for analysis in the metallurgical laboratory.



Tapping an open hearth. Molten steel fills the ladle; the slag spills over into the slag pot.

Teeming ingots. The molten steel is poured into molds where it solidifies.

Open-Hearth Process

More than 90 percent of all steel produced in the United States, including both carbon and alloy grades, is made in *open-hearth furnaces.* The name "open hearth" comes from the fact that the pool of molten metal covered with slag lies on the hearth of the furnace, exposed to the sweep of flames. The excess carbon is oxidized by oxygen from the iron oxide, while the slag absorbs impurities. In this way the molten metal is refined into steel.

Modern open-hearth furnaces are usually about 70 feet long and 20 feet wide. As shown in the diagram, there are doors on the front or *charging side* of the furnace. The back or *tapping* side of the furnace has a tap hole through which the finished steel flows from the furnace into a ladle. This hole is kept sealed with a refractory plug until the steel is ready for tapping.

Air is Preheated in Checker Chambers

Beneath the furnace are two *checker chambers.* They contain bricks arranged in a checkerboard pattern, permitting the alternate passage of air and exhaust gases.

Preheated air from one checker chamber enters at one end of the furnace, where it mixes with gas or other fuel. This air-fuel mixture is blown into the furnace, burning as it sweeps across the pool of molten metal in the hearth. The hot exhaust gases pass out the other end of the furnace into the opposite checker chamber, where they heat the brickwork to a high temperature. Every 10 or 15 minutes the direction of flow is reversed, so that while the brickwork in one chamber is being heated by the hot exhaust gases as they rush from the furnace, the hot checkerwork in the other chamber is heating the air that is entering the furnace.

How the Open-Hearth Furnace Works

First, limestone is put into the furnace. Its purpose in the open hearth is the same as in the blast furnace: it removes impurities and builds up a slag. Next comes iron ore (or some other source of iron oxide) which supplies the oxygen needed to oxidize the excess carbon. Then steel scrap is placed in the furnace. Normally about one-half of the metal charged into the open hearth is scrap and the other half is pig iron. After the scrap has been partly melted, the pig iron, which has been kept in a molten state in a hot-metal mixer, is poured into the furnace. Finally, more iron ore is added, and the melting is continued.

Next follows the *refining* or *purification* period, during which the excess carbon is oxidized and other impurities are absorbed by the slag. The flames sweeping across the surface of the molten metal bring it to a temperature of about 2800 degrees F. This intense heat creates such a dazzling glare that it is impossible to look into an open-hearth furnace without special glasses.

From time to time during the refining period samples are taken of the metal and sometimes of the slag. These samples are rushed to the metallurgical laboratories for quick checking and analysis, which provides information necessary for proper control of the refining operation.

If alloy steel is being made, the alloying materials are added at the proper time.

The entire process of making a heat of steel takes up to 12 hours. When the steel has been refined to the exact specifications called for, the heat is tapped. The plug in the tap hole at the rear of the furnace is punctured with a rocket-like explosive charge. The steel gushes out in a bright stream, down over a spout and into a huge ladle. The slag, which leaves the furnace after the steel, spills over into a smaller container called a *slag pot* or *thimble,* which is later taken to the slag dump.

Molten Steel Poured Into Ingot Molds

Most modern open-hearth furnaces produce from 150 to 250 tons of steel in each heat. After tapping the furnace is charged again and the process is repeated.

Steel made in the open hearth, or in the electric furnace or bessemer converter as described in the following pages, is poured or *teemed* into ingot molds where it cools and solidifies. The ingot is the first solid form of steel. Ingots usually range between 5 and 25 tons, although much larger ingots have been poured for special purposes.

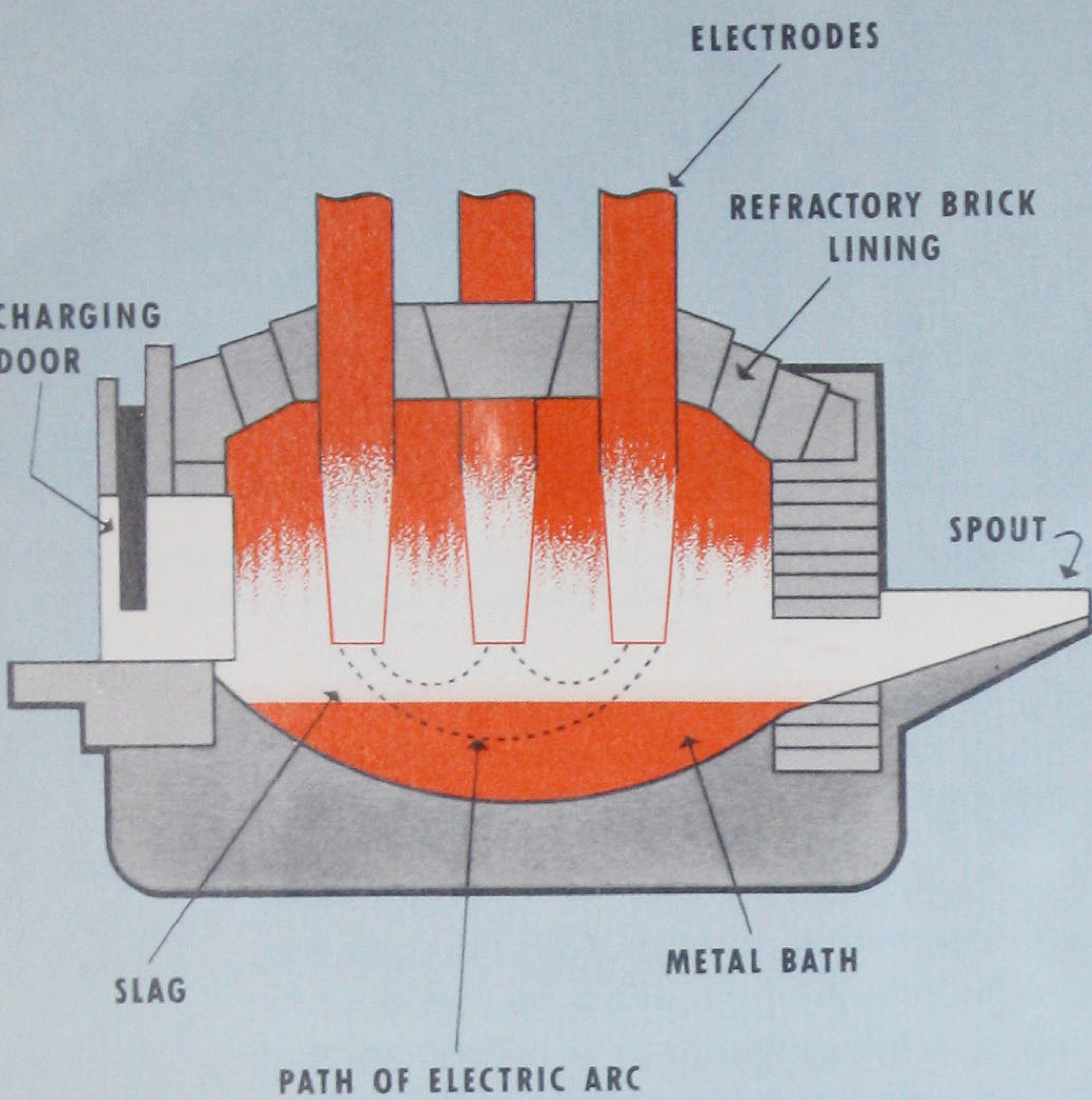
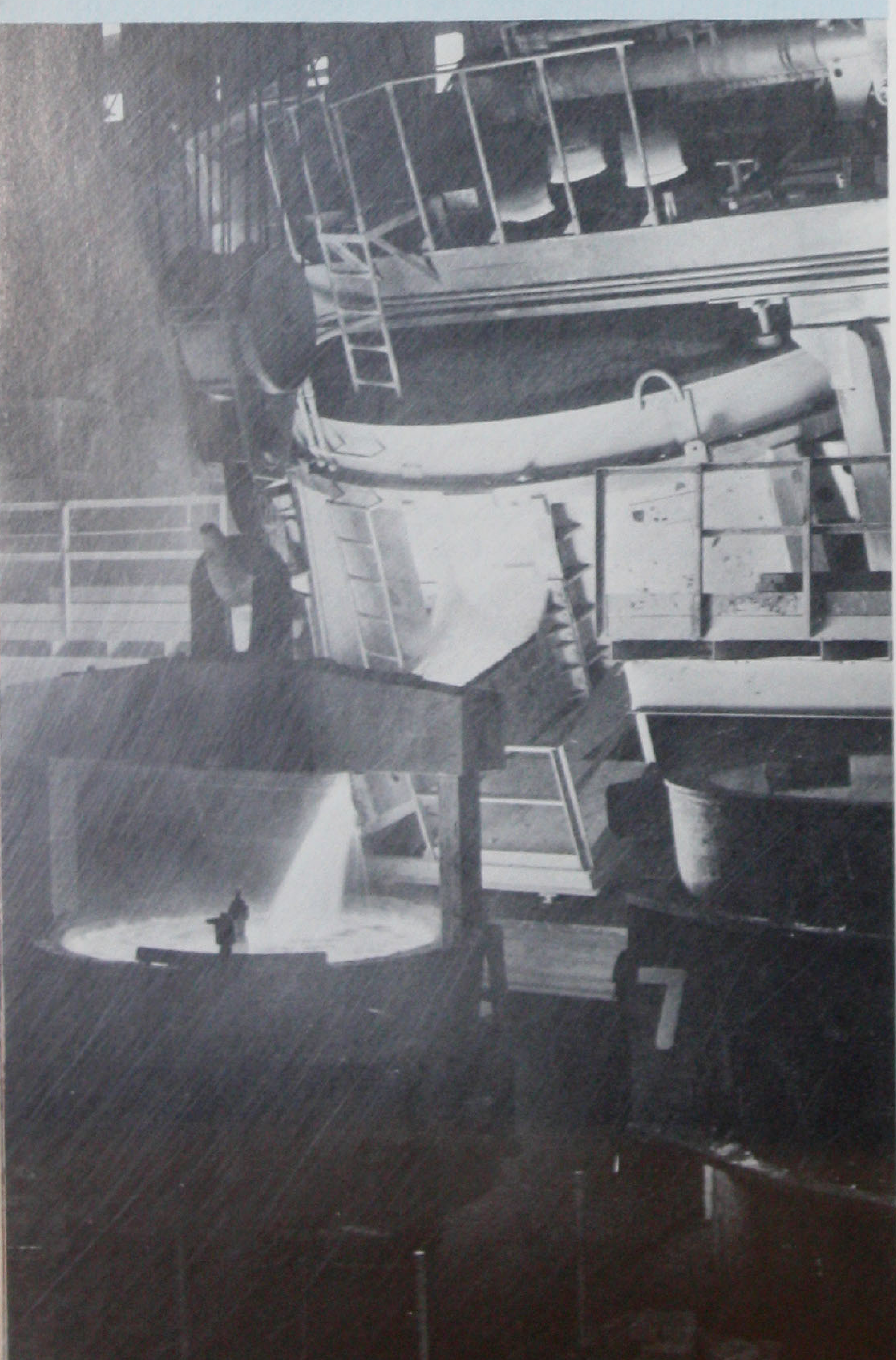


Diagram of arc-type electric furnace. It is nearly round in shape and can be tilted to pour out the finished steel.

Tapping a 75-ton electric furnace at the Bethlehem Pacific Plant in Los Angeles.



Electric-Furnace Process

Most electric-furnace steel is made in furnaces of the *electric-arc type,* in which the "bath" of molten metal is heated by an electric arc. Both the temperature and the atmosphere can be very closely controlled, making the electric furnace ideal for producing steel to exacting specifications: high-alloy steels, stainless steels, or special steels requiring very close metallurgical control.

However, in recent years there has been a growing trend toward the production of carbon steels in the electric furnace, especially in smaller plants, and in locations where large supplies of ferrous scrap are available.

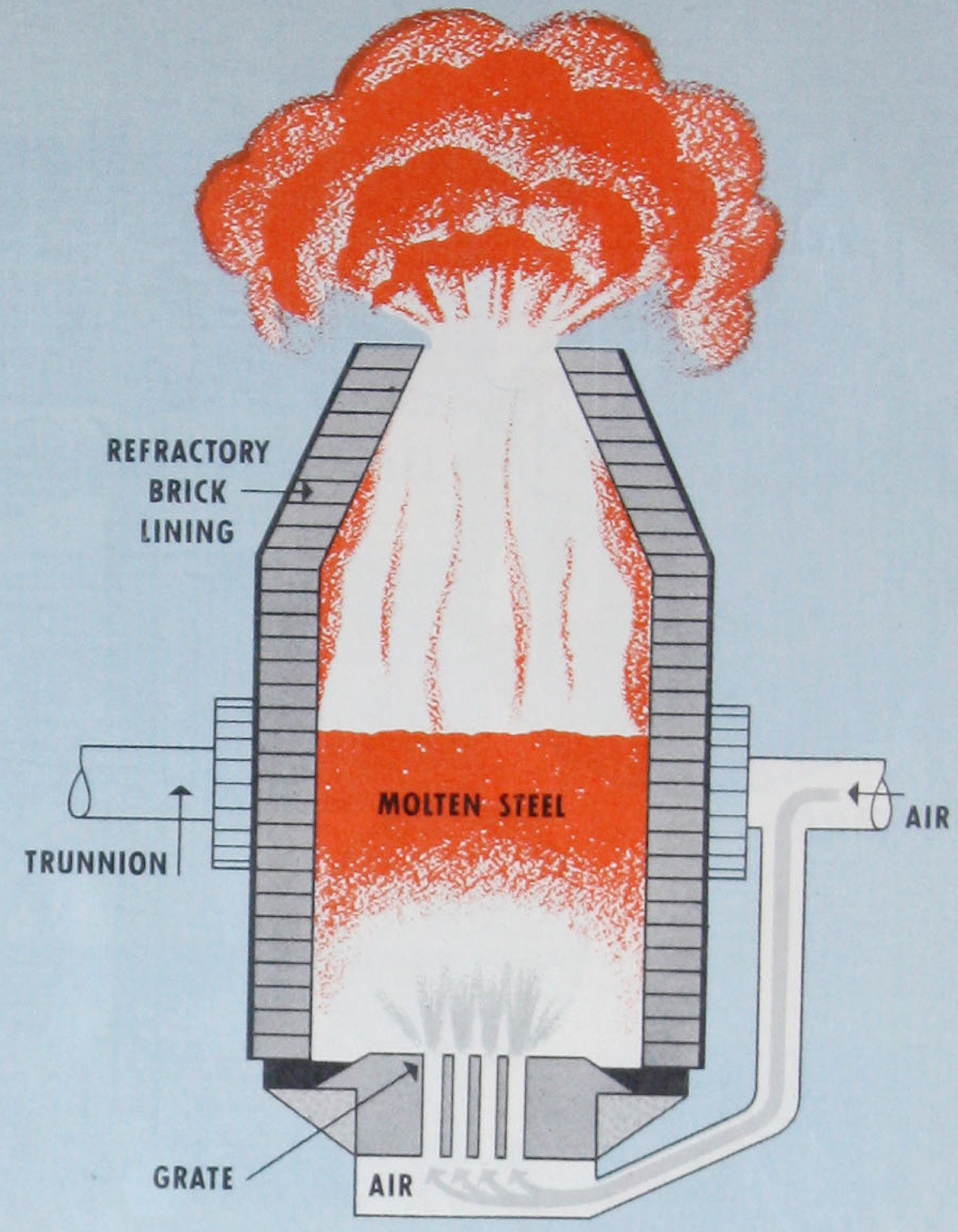
Electric furnaces vary in capacity from 5 to 100 tons. They somewhat resemble a teakettle in shape, and are tilted to pour out the finished steel through a spout. Three carbon electrodes extend down through the roof of the furnace. The metallic charge is inserted through a door on one side or through the top of the furnace which can be swung to one side.

How the Electric Furnace Works

The initial charge consists of carefully selected steel scrap. The electrodes are lowered and the current is turned on. The intensely hot arcs between the electrodes and the scrap quickly form a pool of molten metal directly under the electrodes and, in effect, enable the electrodes to bore into the scrap. After the charge is about 70 percent melted, iron ore and burnt lime are added, and melting is completed. At this point, samples of the bath are analyzed in the metallurgical laboratory.

The next step depends on the kind of steel being made. If it is carbon steel, the operation is rather similar to that of the open hearth. If an alloy steel is being made, the initial slag is removed and a second slag is made to permit close control of the final analysis. All additions to the bath—the materials added to form the second slag and the alloying materials—are in the form of carefully dried material of known composition. The entire process takes from 4 to 12 hours, depending on the type of steel.

Diagram of a bessemer converter. As the metal is refined, brightly flaming gases burst from the mouth of the vessel.



Bessemer Process

Development of the bessemer converter in the 1850's marked the beginning of the modern steel industry. This is the oldest of the three steelmaking processes in use today. In the bessemer process the charge of molten pig iron is refined into steel by blowing air through it, thus oxidizing or burning out undesirable elements.

A bessemer converter, as shown in the accompanying diagram, is a pear-shaped vessel, 10 feet or more high, open at the top, and mounted on trunnions so that it can be tilted. Holes in the bottom permit air to enter and pass up through the charge of molten pig iron. Depending on the size of the converter, between 12 and 30 tons of steel can be made in a 12- to 20-minute "blow."

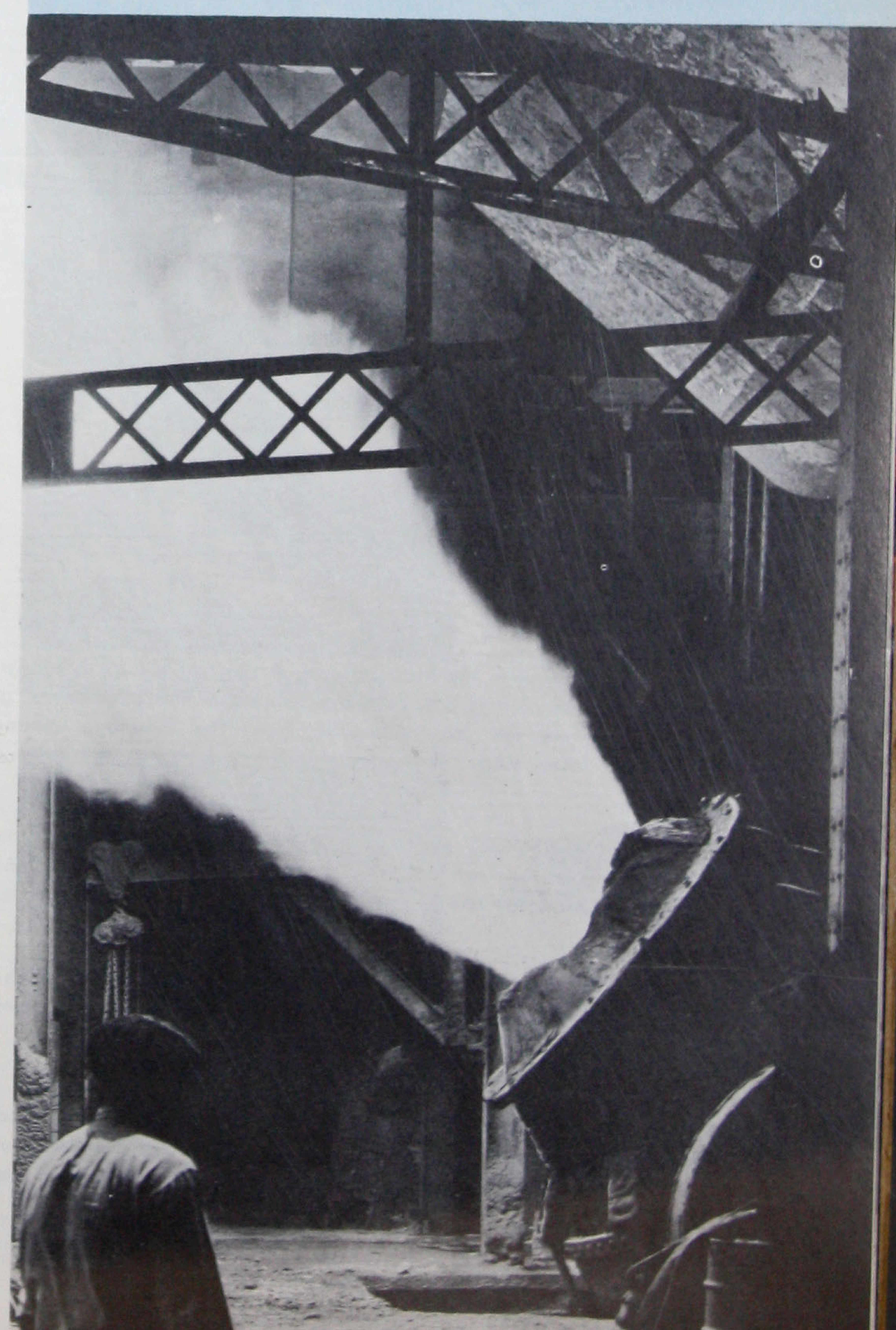
How the Bessemer Converter Works

First, the converter is tilted forward and molten pig iron is poured in at the top. The vessel is then returned to an upright position and a blast of air is blown in at the bottom. As the air passes upward through the pig iron, the oxygen it contains burns out the undesirable elements, forming slag and gases. The gases burst from the mouth of the converter with a brilliant shower of smoke, sparks and flame, making one of the most spectacular sights in steelmaking. When the process has been completed the converter is tilted and the steel poured into a ladle, from which it is teemed into ingot molds.

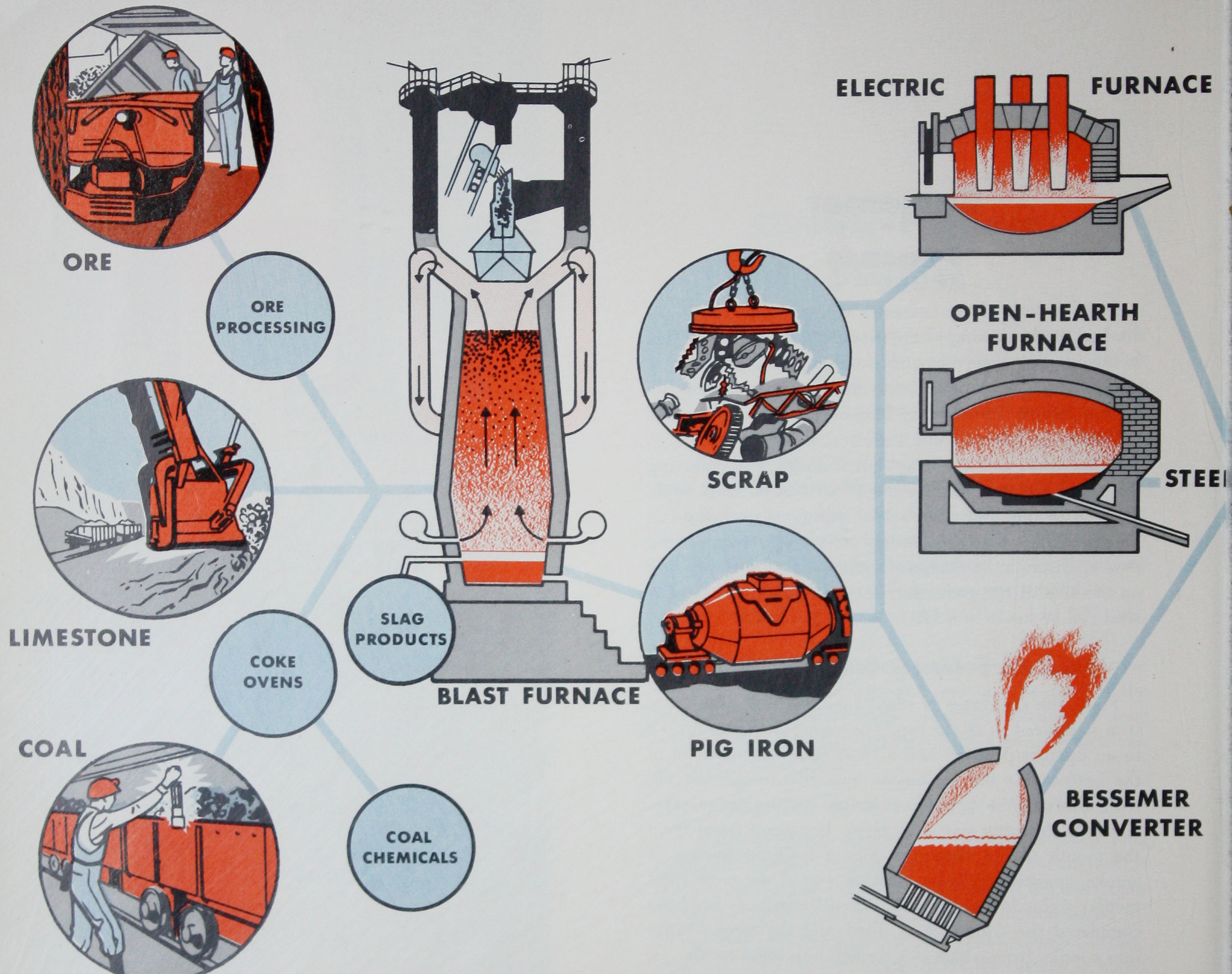
Bessemer Steel 5% of Total

In the early days of the steel industry, up to around the turn of the Century, most steel was made in the bessemer converter. The first steel rails made in this country for our expanding railway system were made from bessemer steel. But today bessemers account for less than 5 percent of all steel produced in the United States. Bessemer steels are used for certain types of free-machining steels, certain types of wire, and some grades of pipe, especially pipe made by butt-welding.

"Blowing" a bessemer at Sparrows Point. This is a very colorful, spectacular sight. ▼



Ore . . to Iron . . to Finished



PIG IRON is produced in the blast furnace. A blast of hot air is blown upward through the charge of iron ore, coke and limestone. The coke burns, giving off gases which reduce the ore to metallic iron. The limestone combines with impurities and forms slag.

OPEN-HEARTH FURNACES produce over 90 percent of all steel. Molten pig iron, cold scrap metal, iron ore and limestone are charged into the furnace. Flames sweep across the hearth, melting the charge and refining the steel.

ELECTRIC-ARC FURNACES are especially suitable for making steel to exacting specifications. The charge of selected steel scrap and limestone is melted, and the molten metal is refined by heat from the electric current.

BESSEMER CONVERTERS produce about 5 percent of all steel made in the United States. Air is blown through the charge of molten pig iron, burning out the undesirable elements which escape as gases or are removed as slag.

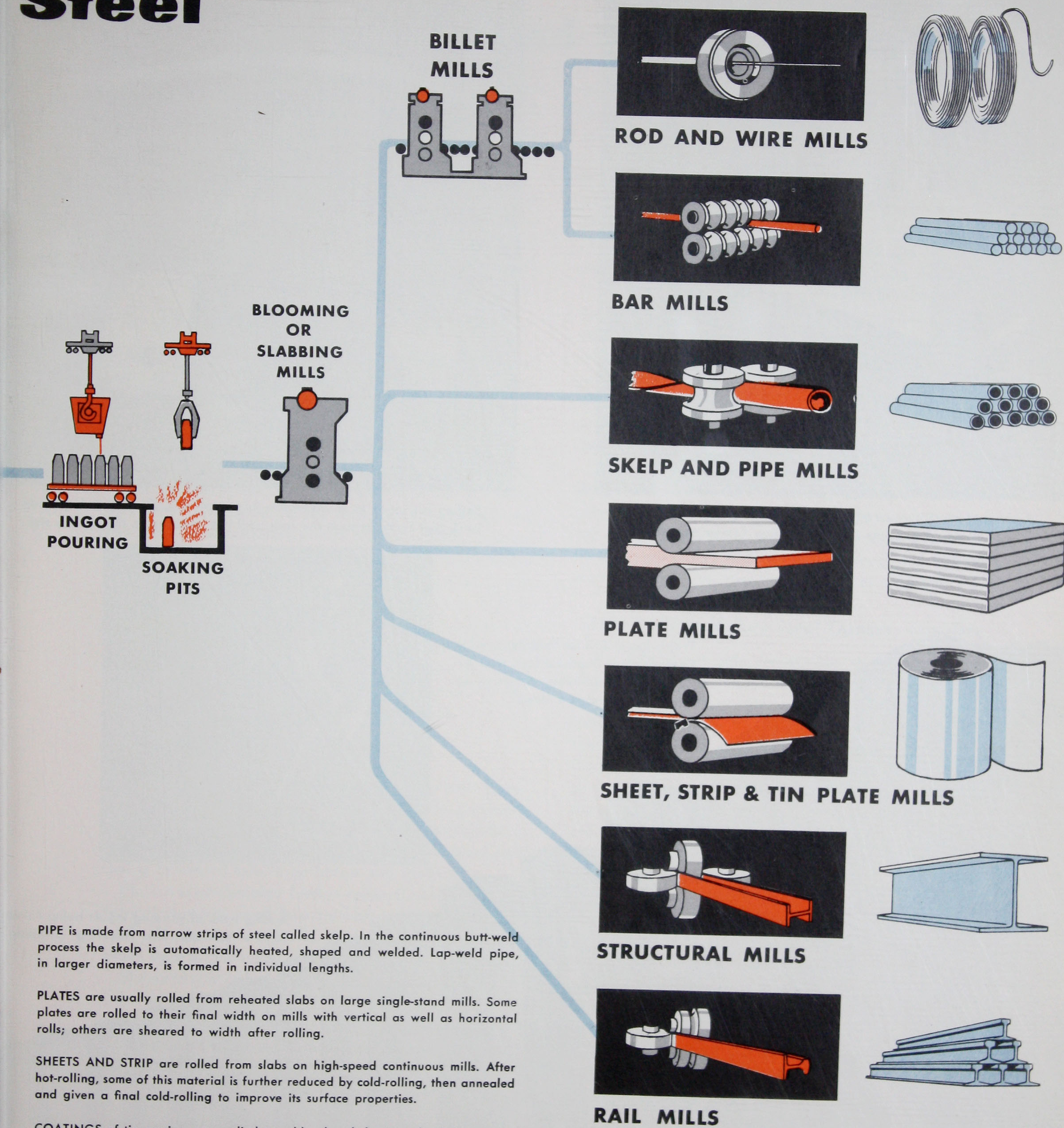
INGOTS are made by pouring molten steel into cast-iron molds. After the steel has solidified, the ingots are removed from the molds and prepared for rolling by reheating in soaking pits until the temperature in every part of the ingot is the same.

SEMI-FINISHING means the rolling of ingots into blooms or slabs. Sometimes blooms are rolled into smaller sections, called billets. The semi-finished steel — bloom, billet or slab — is then further rolled into the finished product. Rolling not only shapes the steel but also improves its mechanical properties.

WIRE is made from coiled rod produced from billets on high-speed continuous rod mills. The rod is drawn through a series of dies of gradually diminishing size to the required gage. Some wire is then coated with zinc.

BARS are hot-rolled from billets. Each pass through the rolls elongates and further reduces the billets in cross-section. Grooves in the surface of the rolls produce the proper bar shape.

Steel



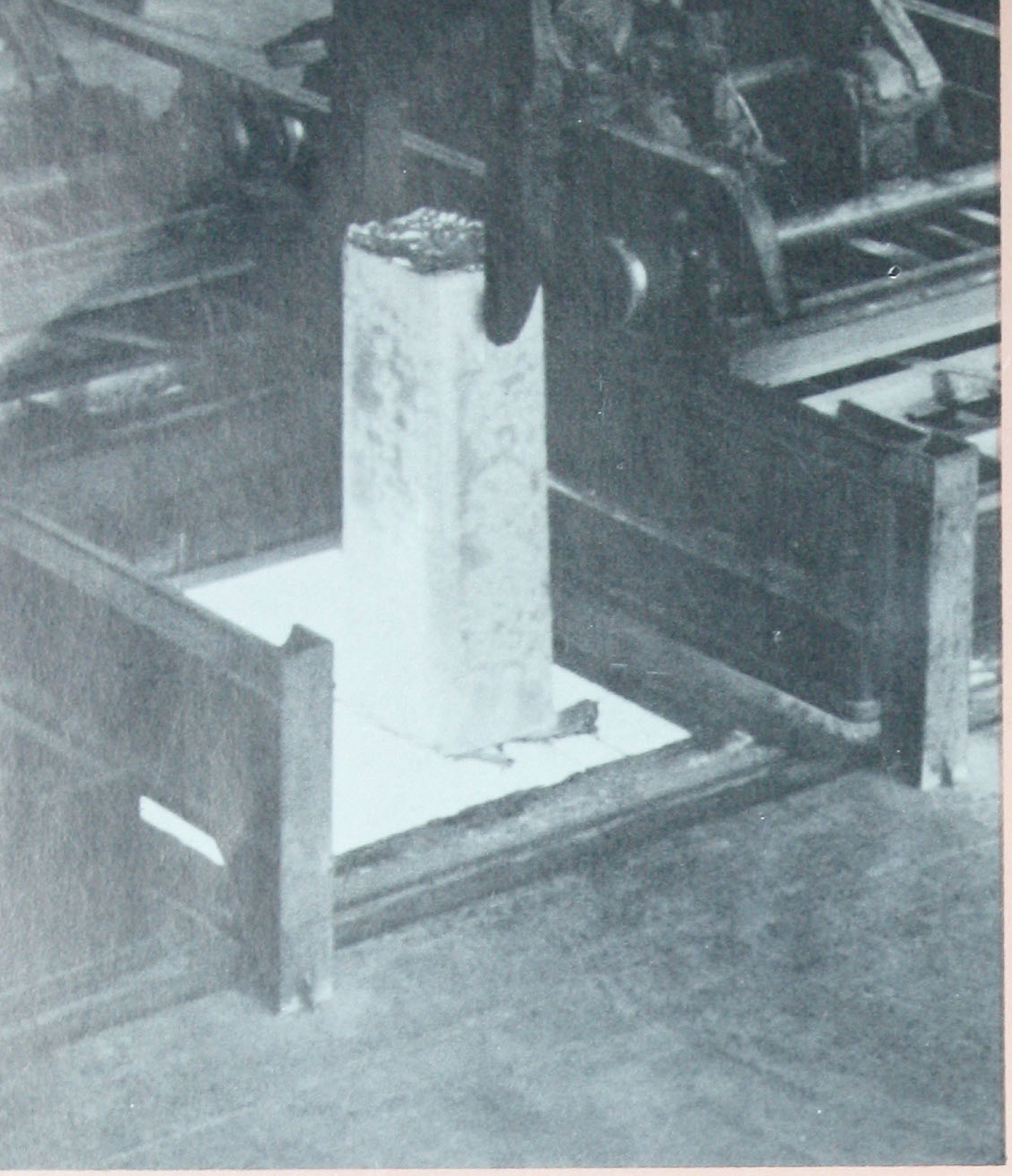
PIPE is made from narrow strips of steel called skelp. In the continuous butt-weld process the skelp is automatically heated, shaped and welded. Lap-weld pipe, in larger diameters, is formed in individual lengths.

PLATES are usually rolled from reheated slabs on large single-stand mills. Some plates are rolled to their final width on mills with vertical as well as horizontal rolls; others are sheared to width after rolling.

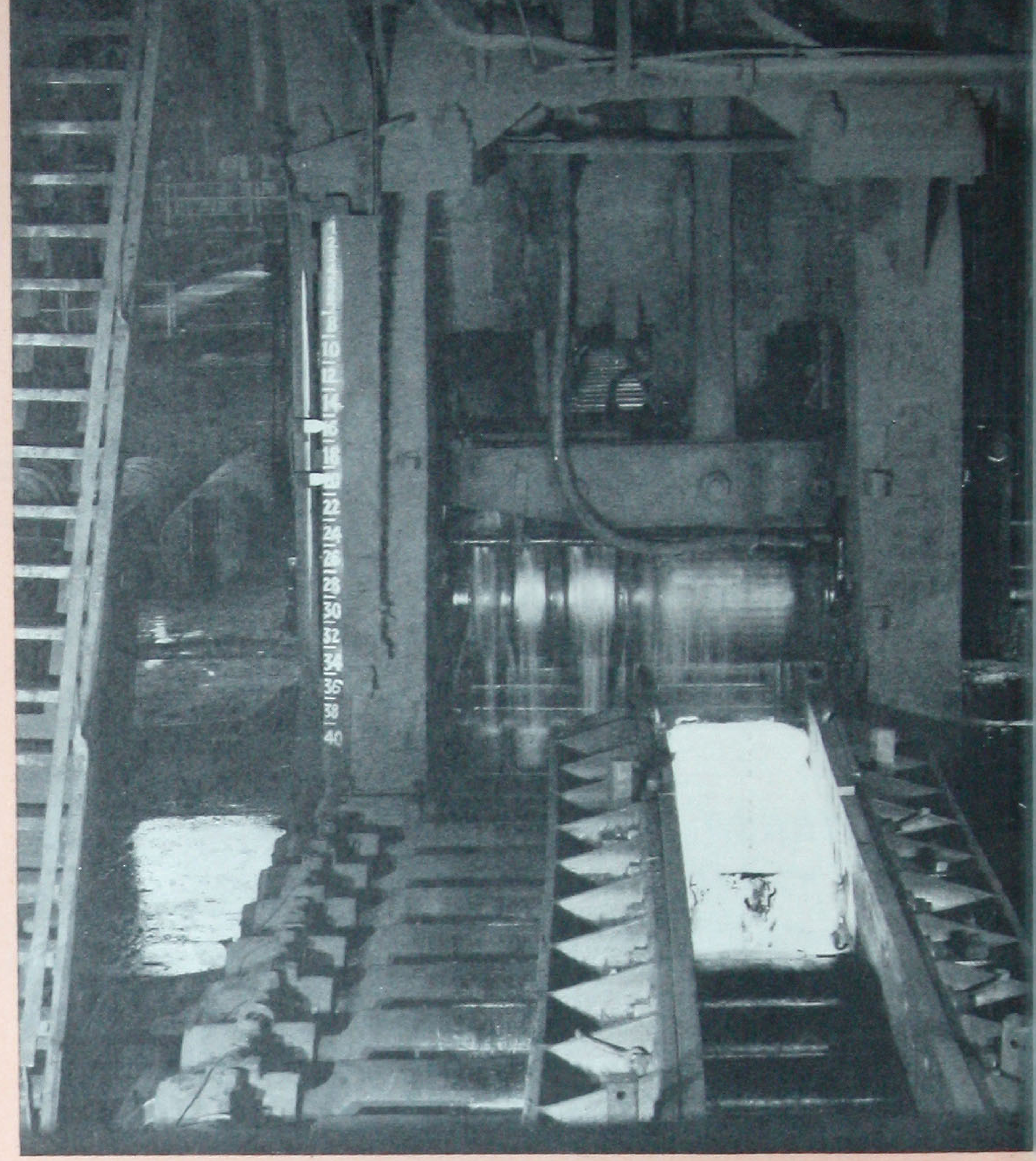
SHEETS AND STRIP are rolled from slabs on high-speed continuous mills. After hot-rolling, some of this material is further reduced by cold-rolling, then annealed and given a final cold-rolling to improve its surface properties.

COATINGS of tin or zinc are applied to cold-reduced sheets and strip to protect the steel against corrosion. Steel sheets coated with tin are known as tin plate, and those coated with zinc are called galvanized sheets.

STRUCTURAL STEEL and RAILS are rolled from blooms. Standard structural shapes are produced on mills equipped with grooved rolls. Wide-flange sections are rolled on Grey mills which have ungrooved horizontal and vertical rolls.



Powerful tongs lifting an ingot from the soaking pit where it was thoroughly heated to the rolling temperature.



Rolling an ingot in a reversible blooming mill. The ingot is passed back and forth through the rolls until it is reduced to the proper size.

Preparing a slab for finishing operations. Surface imperfections may be removed by grinding, chipping, or by burning as shown here.

A long train of glowing ingots being taken to the soaking pits following stripping.

Making Finished Steel Products

Steel leaves the open-hearth, electric-furnace and bessemer departments in the form of ingots. The sections of this book that follow describe how ingots are made into *finished steel products* — plates, strip, sheets, tin plate, bars, structural steel, wire, pipe and rails.

Broadly speaking, ingots are processed into finished steel products in two steps. First, the ingot is reduced in cross-section by hot-rolling it into *semi-finished steel products — blooms, billets* and *slabs.* Second, the blooms, billets and slabs are processed into finished steel products.

Preparing the Ingot for Rolling

After the molten steel has been poured or *teemed* into ingot molds, it is allowed to cool to the point where it solidifies. At the proper time, the ingot mold is removed from the ingot by "stripping." A special crane grips the mold and lifts it away from the metal. Sometimes the process is reversed, and the metal is lifted out of the mold.

The outside of the ingot naturally cools and solidifies faster than the inside. At the time the mold is removed the ingot is comparatively cool on the outside, but the interior is still extremely hot, usually in a semi-molten condition. Before the ingot can be rolled, the outside and the interior must be at the same temperature. This is done by soaking it in heat in a *soaking pit.* Soaking pits are gas-fired furnaces where the ingot is heated to about 2200 degrees F and kept at that temperature for from four to eight hours. It is then evenly heated, and soft and plastic enough to be shaped by the rolling mills.

Blooms, Billets and Slabs

Semi-finishing mills are of three principal types: *blooming mills, billet mills* and *slabbing mills.* As shown in the diagram, blooms are either square or rectangular in cross-section. Blooms are the form of semi-finished steel that is processed into large beams and girders.

Blooms are sometimes further reduced in size to billets before being processed into finished products. Billets are used to make bars and rod. Rod is the material from which steel wire is made.

Slabs are relatively flat, their width being three, four, or more times their thickness. Slabs are used to make plates, strip, sheets and other flat-rolled steel products.

Blooms and slabs are made by squeezing the hot, plastic ingot between two horizontal steel rolls rotating in opposite directions. The distance between the rolls is adjusted so that the rolls are always slightly closer together than the thickness of the steel passing through. The ingot gets longer and thinner as it passes between the rolls.

The rolls are mounted in heavy housings, or *roll stands.* A stand with two rolls is referred to as *two-high;* a stand with three rolls, one above the other, is *three-high.* The ingot is carried to and through the stands on a path of rollers. These rollers, which are rotated by electric power, are mounted on the long table of the mill.

Blooms and slabs are frequently made on two-high *reversing* mills. Since the direction of rotation of the rolls can be reversed, the ingot is passed back and forth between the rolls, which are brought closer together at each pass, until the steel has been reduced to the desired cross-section. Three-high mills are not reversible. The ingot is passed between the bottom and middle rolls, then raised and passed between the middle and top rolls.

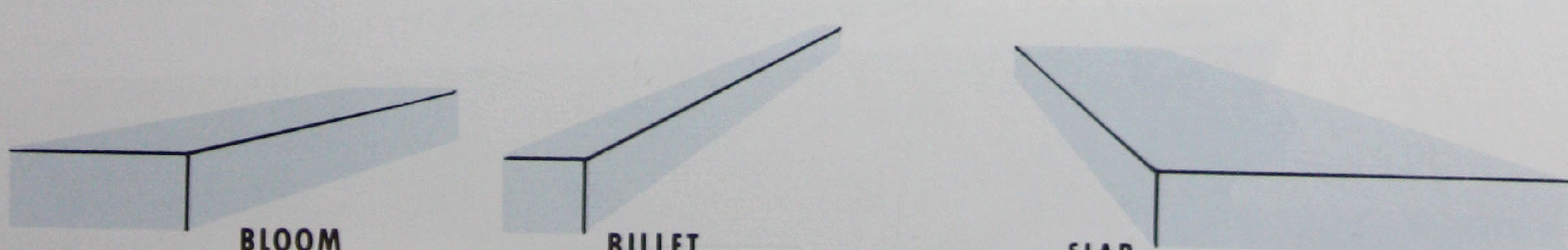
Billet mills, on the other hand, are often of *continuous* design. That is, the mill consists of a series of roll stands (each of which is much smaller than the stands in blooming and slabbing mills) arranged one after the other so that the steel to be rolled passes successively through each stand and emerges from the last stand as a finished billet.

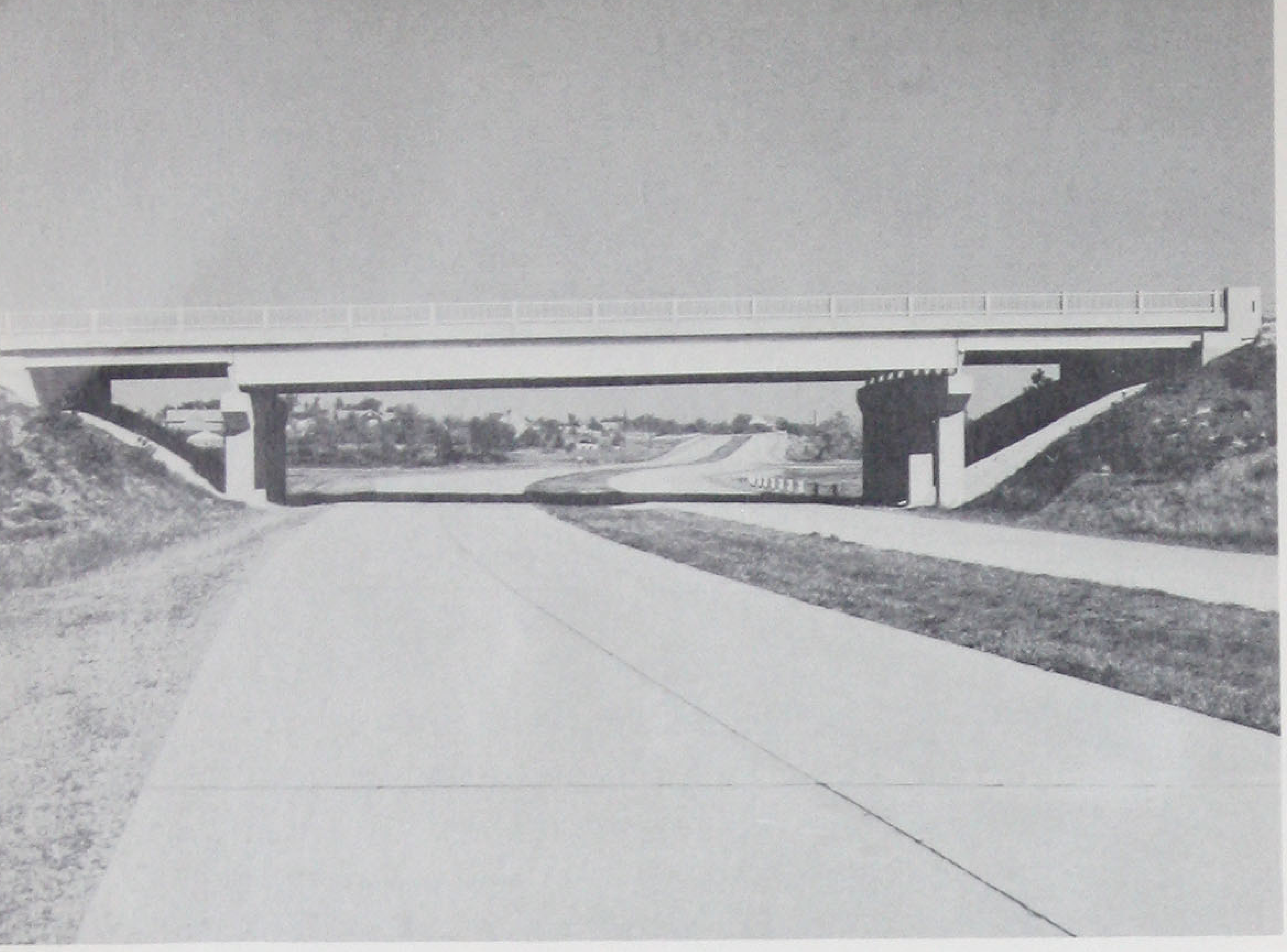
Hot-Rolling Makes Steel Denser, Tougher

Hot-rolling not only reduces the steel to the desired shape and size but improves its quality. Steel consists of a mass of metallic crystals or grains. In the ingot these grains are relatively large and are distributed in a way that causes poor mechanical properties. Hot-rolling breaks down the grains into smaller particles, making the steel denser, tougher and more malleable. The quality of the steel is improved in this way not only while the ingot is being reduced to bloom, billet or slab, but also during the finishing processes that follow.

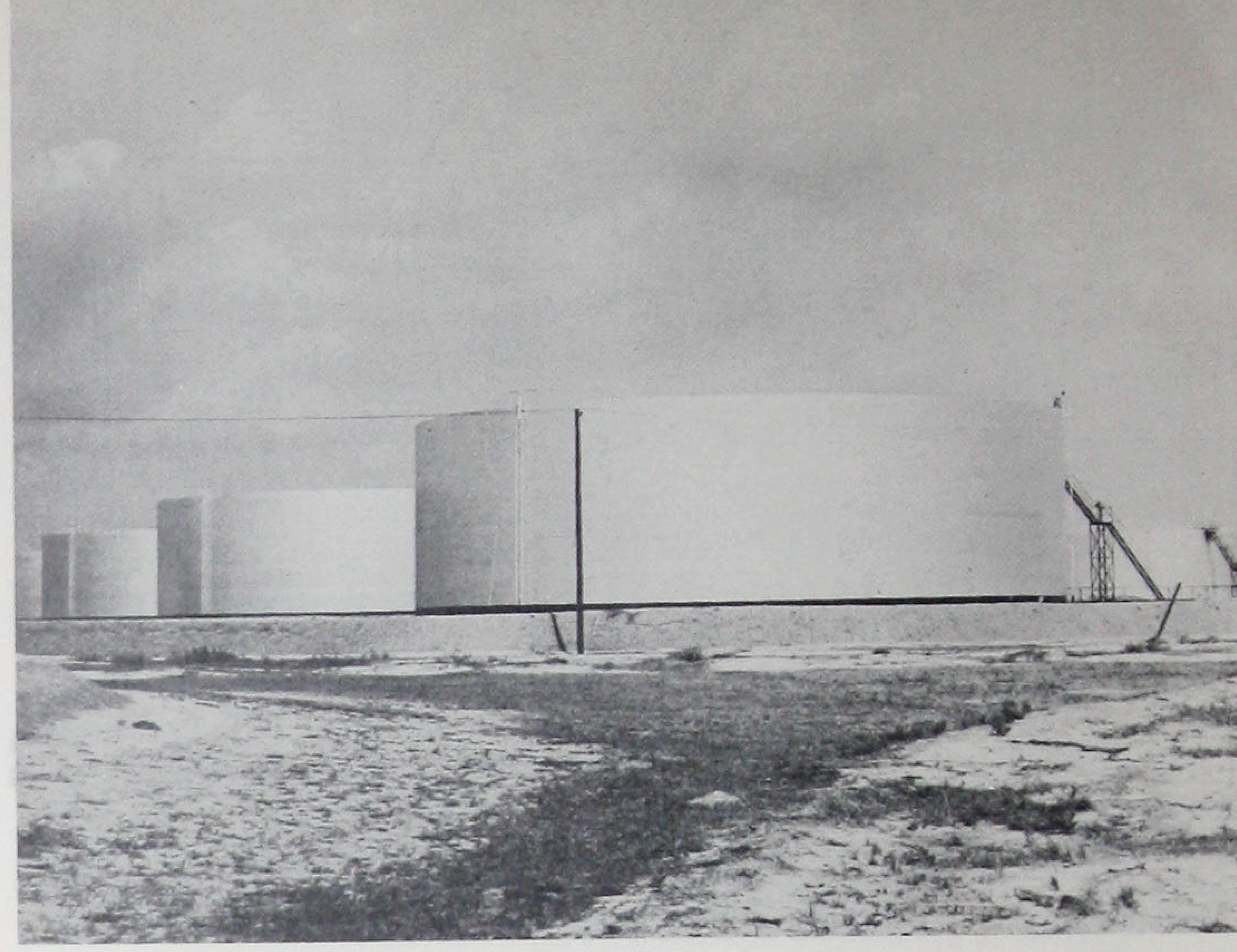
After the blooms and slabs have been rolled their irregular ends are cut off or *cropped* by powerful shears. The cropped ends contain certain irregularities which if not eliminated would cause imperfections in the finished product. The discarded ends are used as scrap in the steelmaking furnaces.

After they have been cut into shorter lengths that are more easily handled in the finishing mills, the blooms, billets and slabs are carefully inspected for defects. The inspector marks all surface flaws for removal by grinding, chipping, burning or scarfing.

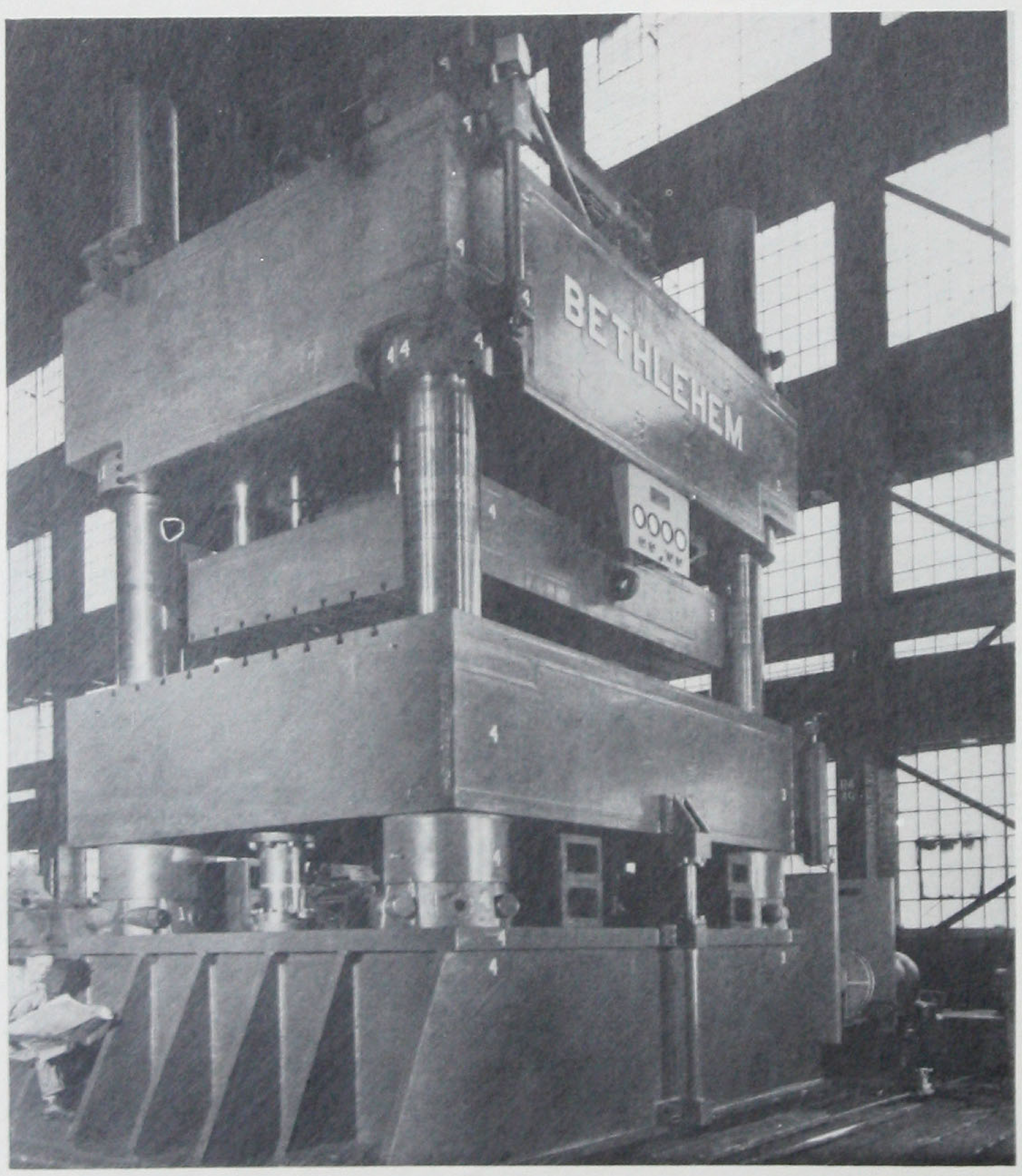




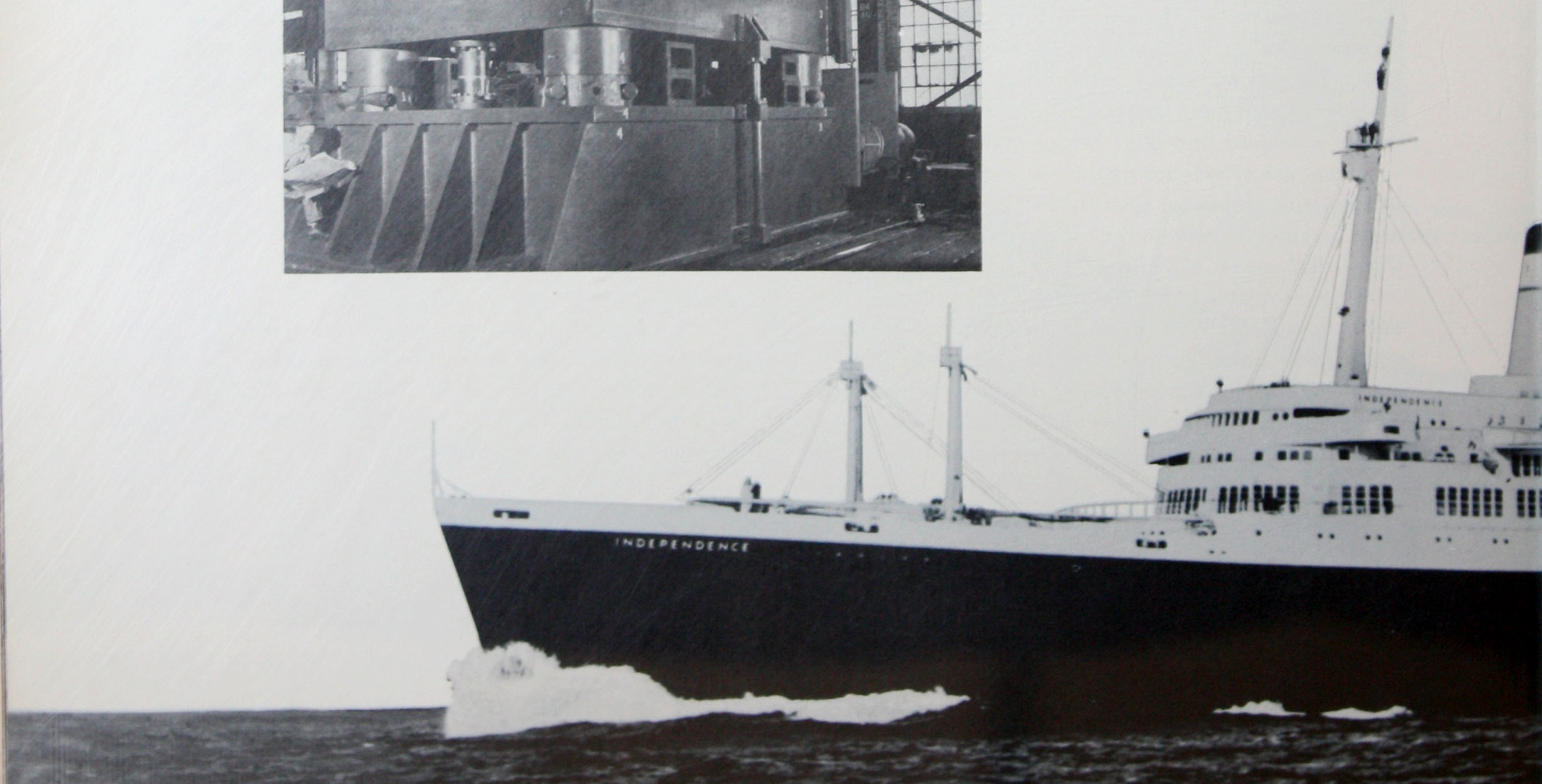
Highway and railroad bridges are often built largely of girders made up of riveted or welded steel plates and angles.

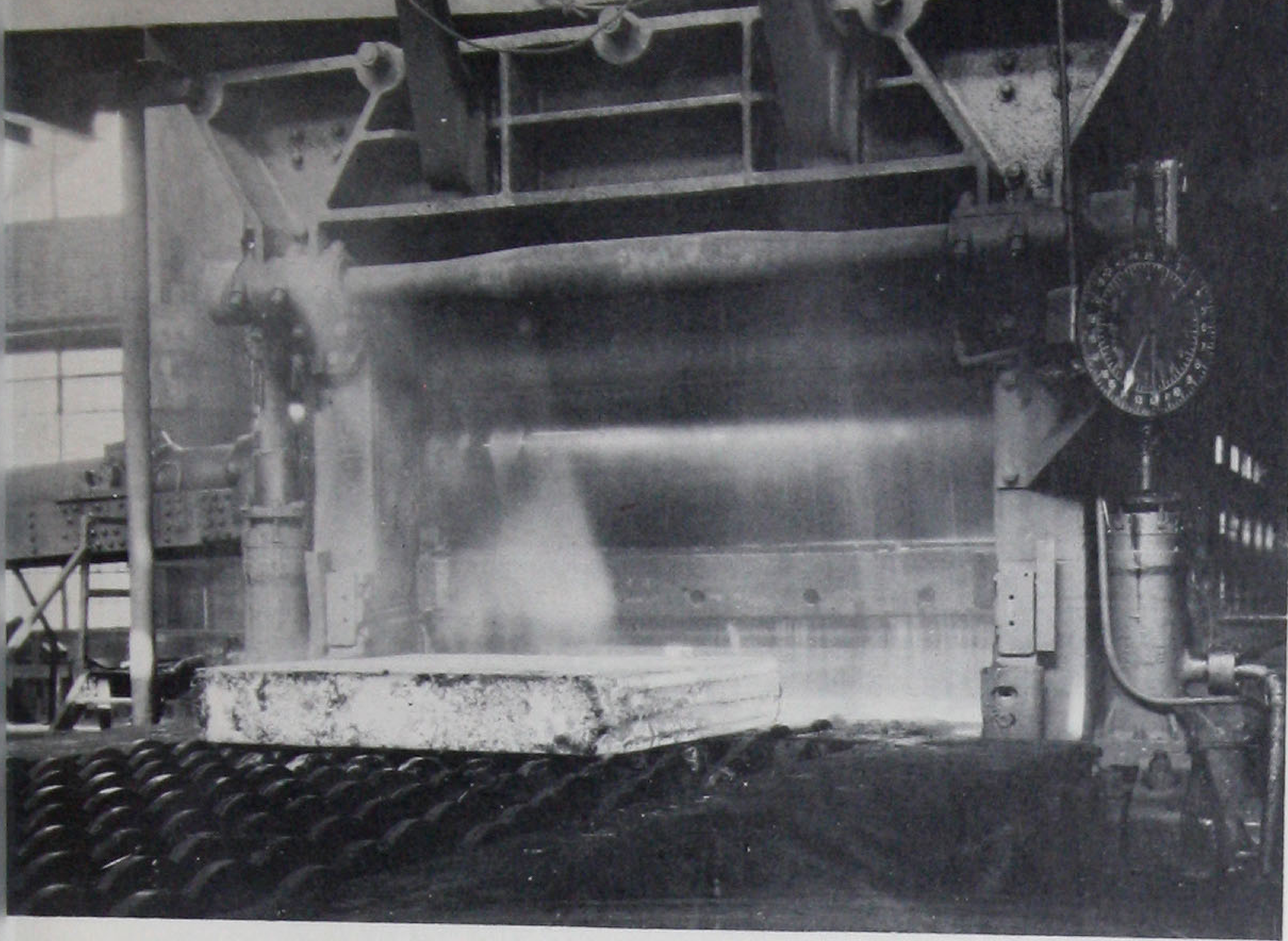


These huge oil storage tanks, as well as water tanks, propane tanks, gas holders and boilers, are fabricated from steel plates.

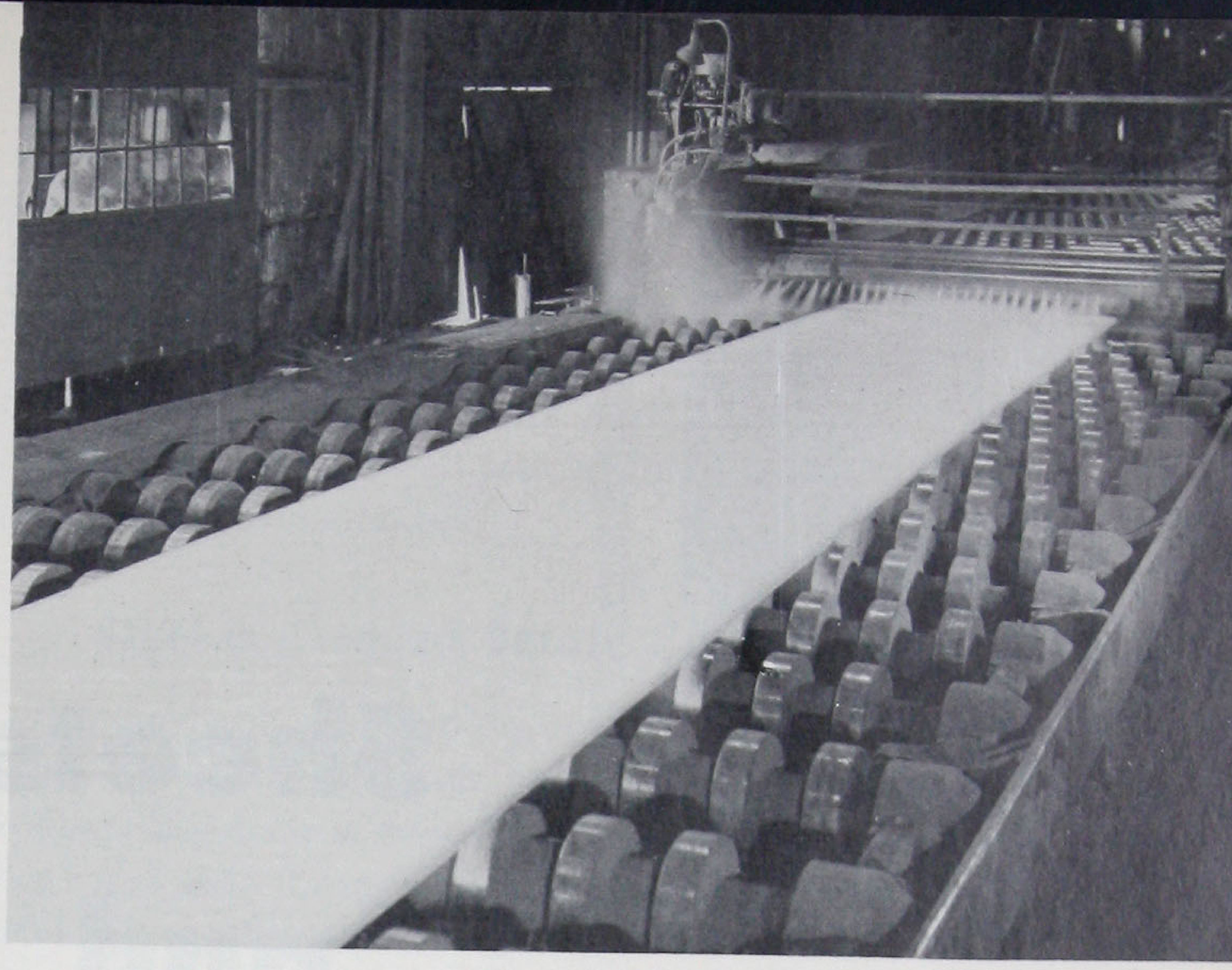


This giant hydraulic press was made chiefly from steel plates welded together. The bases, frames and many moving parts of light and heavy machinery are often fabricated from plates.





Slab entering sheared-plate mill at the Sparrows Point Plant. This thick slab will be rolled down to less than ½ inch in thickness.



After rolling, the plate passes through special leveling rolls while still hot, making it perfectly straight and flat.

Plates

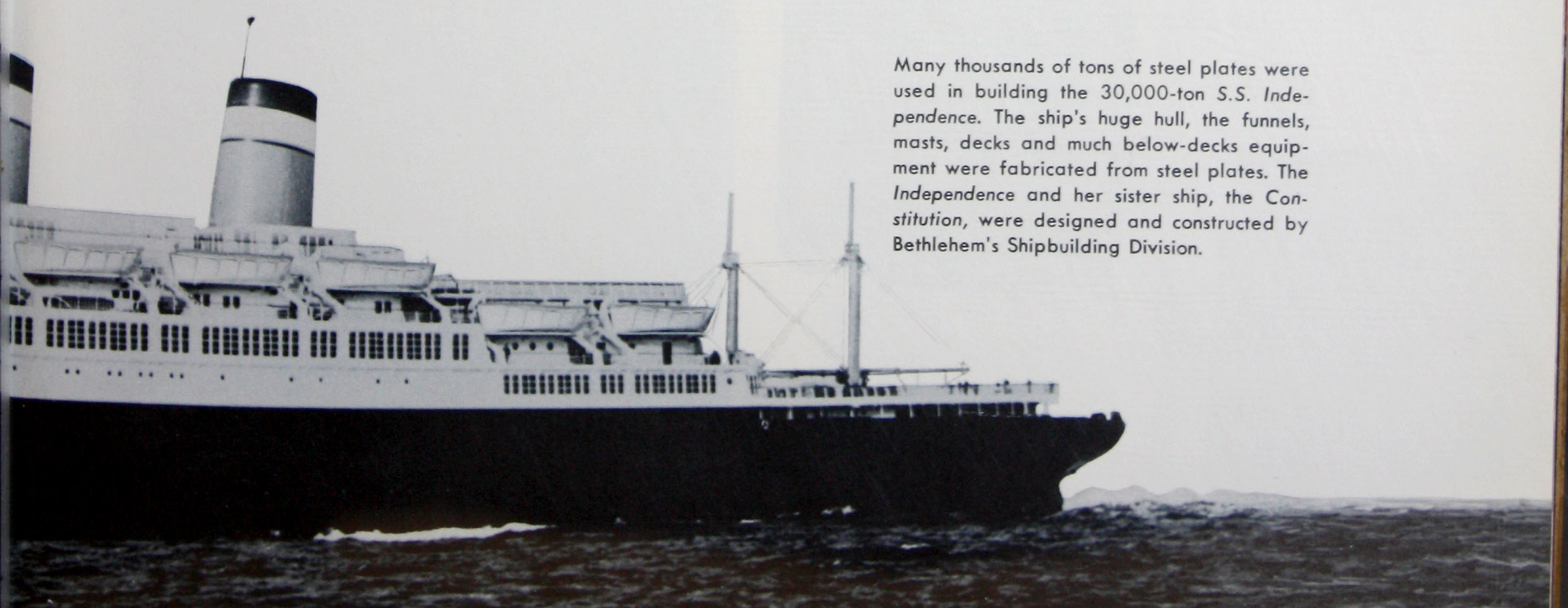
Plates are one of the basic forms of finished steel. They range in thickness from about 3/16 inches to over 12 inches. Girders and other components of bridges and buildings are often made from plates, as are the hulls and decks of many seagoing vessels. The bases that support large machines, as well as many machinery parts, are frequently made from plates. Boilers, oil and water storage tanks, gas holders and propane tanks; large-diameter pipe for water, oil and natural gas, and innumerable varieties of industrial processing equipment, are other typical examples of steel-plate construction.

Two Methods of Rolling Plates

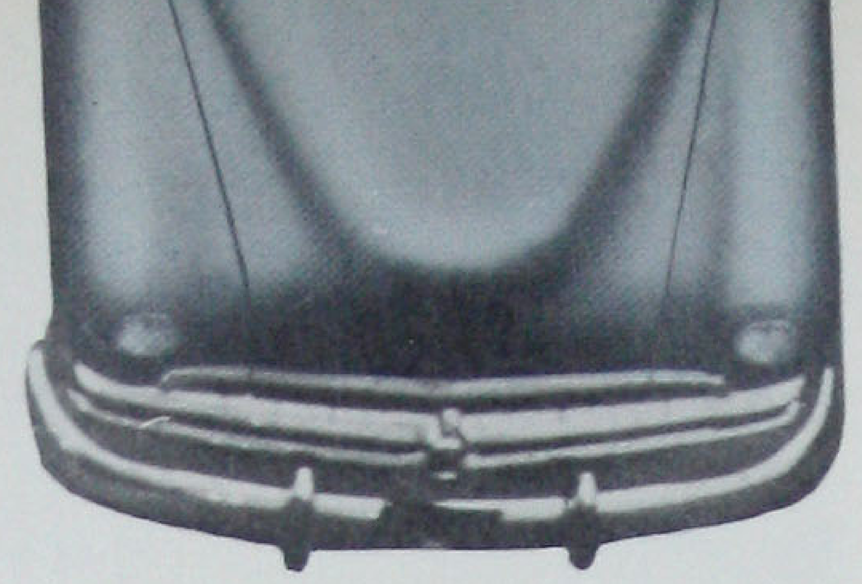
Plates are rolled from slabs on either of two types of plate mills: *sheared* or *universal.* Plates produced on sheared-plate mills must be cut on all sides to the desired dimensions after rolling. Universal-plate mills, having a set of vertical *edging* rolls in addition to their horizontal rolls, roll plates to accurate width, with straight and parallel rolled edges, so that shearing is not necessary.

A substantial tonnage of plates, usually in the lighter gages, is produced on the continuous strip mill, which is described in the following section.

Before it is rolled the slab is placed in a furnace where it is slowly heated to the rolling temperature. At the proper time the hot slab is removed from the furnace and taken to the universal or sheared-plate mill where it is rolled and is made perfectly flat by passing it through a set of leveling rolls. Finally, plates made on the sheared-plate mill are sheared to size.



Many thousands of tons of steel plates were used in building the 30,000-ton *S.S. Independence.* The ship's huge hull, the funnels, masts, decks and much below-decks equipment were fabricated from steel plates. The *Independence* and her sister ship, the *Constitution,* were designed and constructed by Bethlehem's Shipbuilding Division.



Sheets and Strip

Of all the forms of finished steel products, none is more widely used than *sheets* and *strip*. Automobile and truck manufacturers use huge quantities of steel sheets and strip for auto bodies, hoods, fenders and door panels. Many types of metal furniture — desks, chairs, and filing cabinets — are made from steel sheets. So are household appliances — refrigerators, ranges, washing machines and cabinets — as well as metal containers, like barrels and drums, and an endless variety of parts for many kinds of mechanical equipment.

The Continuous Mill in Action

The first step in making sheets and strip is hot-rolling on the *continuous hot-strip mill*, one of the production marvels of our time.

First, the slab is heated to the proper rolling temperature. The glowing slab is pushed from the furnace onto a line of revolving rollers which carry it to the scale-breaker, a set of rolls which breaks up the oxide scale formed on the surface of the slab during heating. A powerful water spray then washes away the loose scale.

The slab moves through the roughing stands which squeeze it down to about one-fifth its original thickness, and stretch it to about five times its original length.

From the roughing stands the slab passes through a second scale-breaker and also a shear which cuts off the uneven ends formed during roughing.

Next, the slab enters the *finishing stands* — a series of six huge roll stands. When it enters these stands it is from

Strip emerging from the hot-strip mill at Sparrows Point. In the background, a roughed slab approaches the finishing stands.

60 to 70 feet long. It leaves the stands as 600 to 700 feet of hot-rolled strip. Since each stand reduces the strip by about one-third in thickness, each succeeding set of rolls must be adjusted to run half again as fast as the preceding set. The steel lengthens so rapidly that before the trailing end of the strip has entered the first stand, the leading end has passed through all six stands, raced down the long runout table at a speed of from 20 to 25 miles per hour, and reached the automatic coiling machine, about 1200 feet from the heating furnaces.

A trap door directs the fast-moving strip down into the coiler, which is located beneath the runout table. In less than 20 seconds the ribbon-like strip is wound tightly into a heavy coil. The coil is ejected, then placed on a mechanical conveyor which carries it to storage.

Sometimes the strip is cut into sheets instead of being coiled. This is done by a *flying shear* located immediately back of the last finishing stand. The shear, which is equipped with rotating knives, automatically cuts the strip into sheets of the desired length. These sheets then travel down the long runout table to be stacked by an automatic piler.

Further Rolling on Cold-Reduction Mill

Much of the strip rolled on the continuous hot-strip mill is further processed on the *cold-reduction mill*, which can produce thinner steel than it is feasible to roll on the hot mills. Cold rolling also finishes the strip to more accurate dimensions and gives it a smooth, bright surface. Cold-reduced sheets, generally after further processing, can be drawn or pressed into a wide variety of shapes such as automobile bodies.

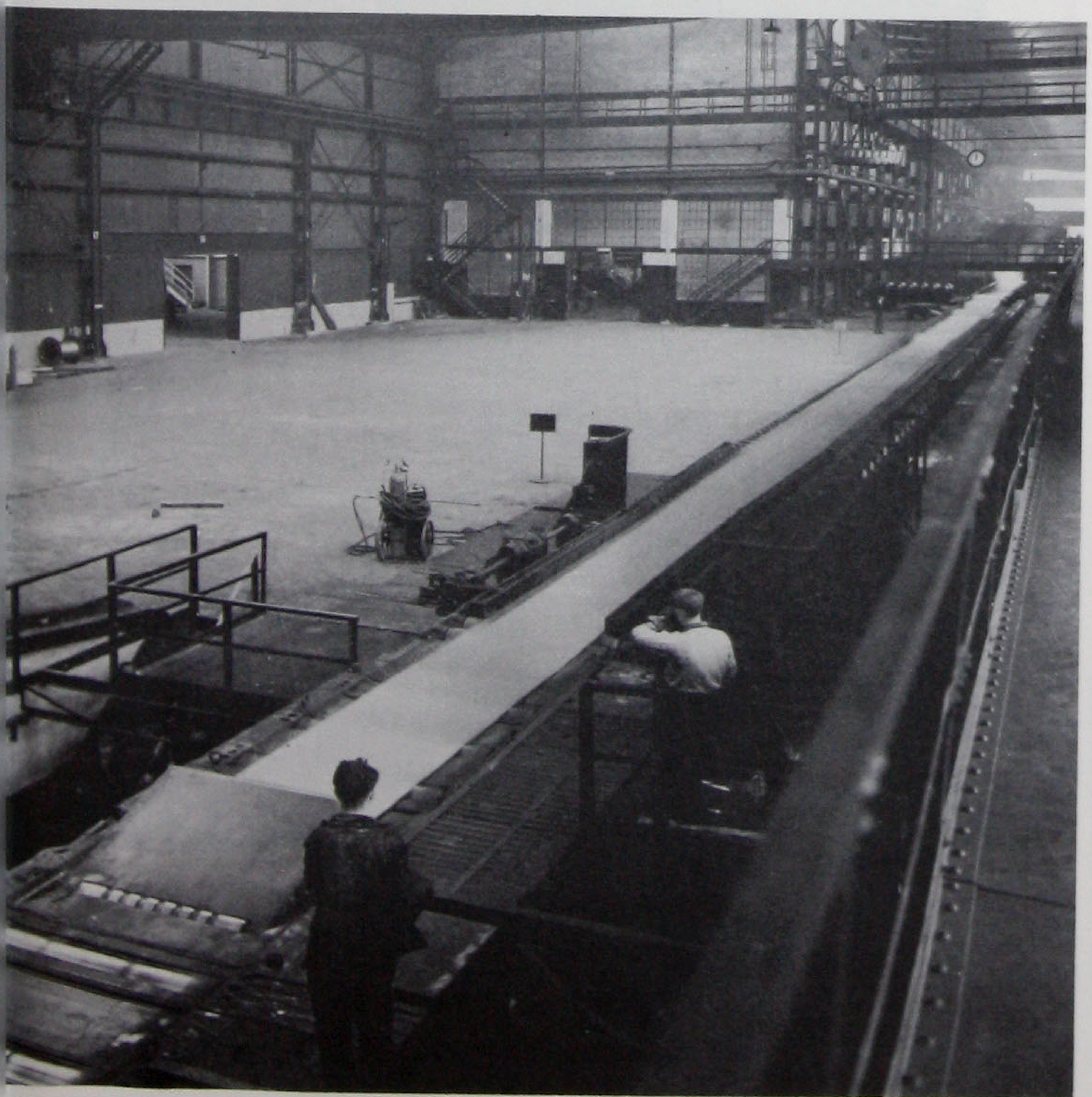
Steel is Cleaned Before Cold-Rolling

The cold-reduction process requires that the metal be quite clean and free of the scale that forms during hot-rolling. This scale is removed by *pickling*, or passing the hot-rolled strip through a hot solution of dilute sulphuric acid. After pickling, the steel is washed, first in cold water, then in hot water and in steam, to remove any remaining traces of scale and acid. Then the strip passes between two rubber rolls which squeeze off the water. It is dried by jets of warm air, and is lightly coated with oil to prevent rusting.

Cold reduction is usually done on three-, four- or five-stand, four-high mills. By sheer pressure the huge rolls reduce the cold steel to perhaps one-tenth its original thickness. The process is so fast that up to 3500 feet or more of cold-rolled strip can be produced per minute.

After leaving the cold-reduction mill, the strip, now with a smooth, lustrous surface, is coiled again and may later be sheared to sheet sizes.

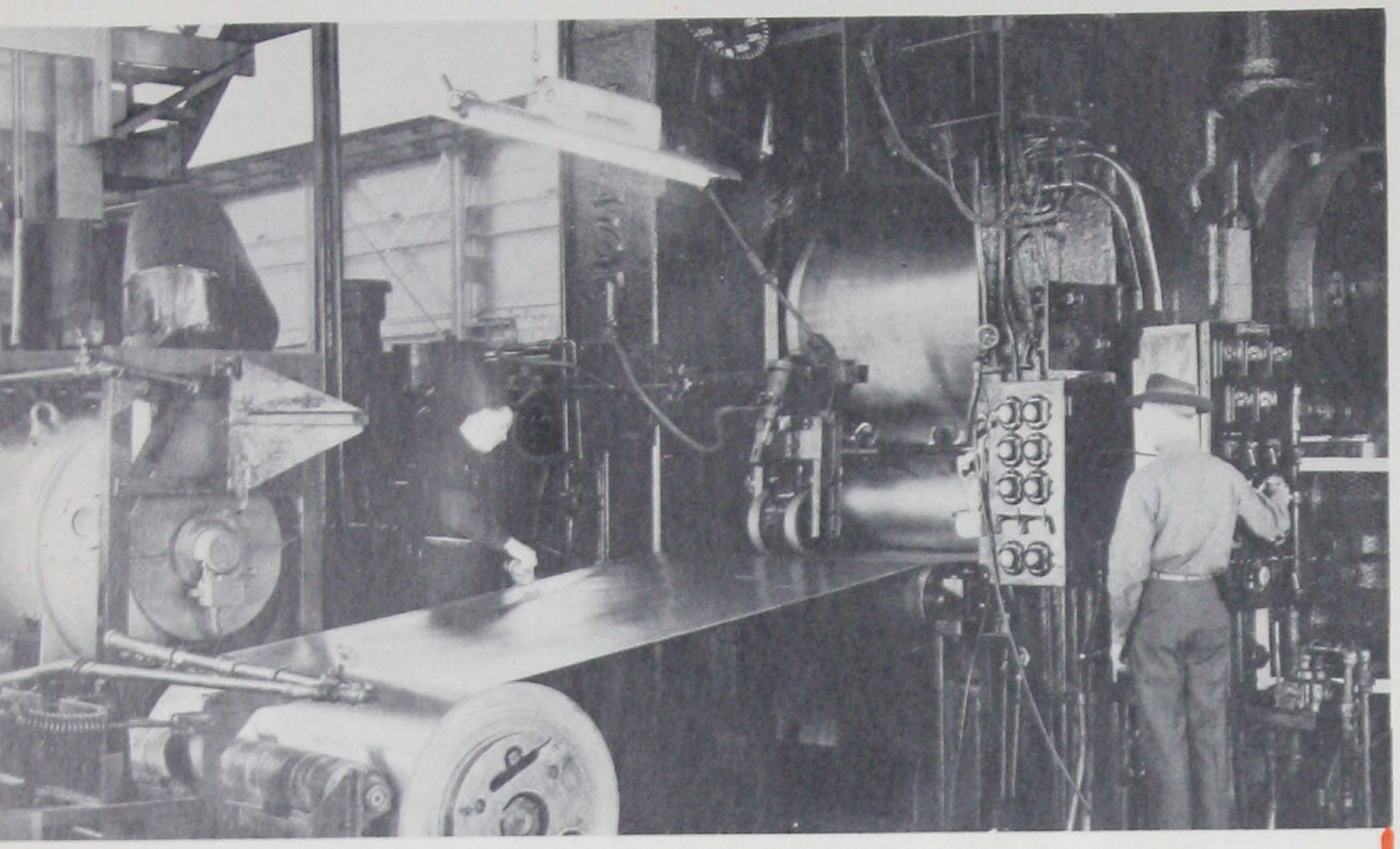
A great deal of cold-rolled sheet and strip, particularly of the lighter gages, is coated with other metals—zinc or tin. Zinc-plating or *galvanizing* and tin-plating are described on the following pages.



Hot-rolled strip speeds at 25 miles per hour down the runout table of the continuous hot-strip mill, through a trapdoor to the coiler.

The enameled panels of many household appliances, stoves, refrigerators and cabinets are made from hot-rolled, cold-reduced sheets.

Cold-rolled strip is softened by annealing, then passed through this single-stand skin-pass mill. Skin-passing stiffens the steel and gives it a highly polished surface.



Annealing and Skin-Pass Rolling

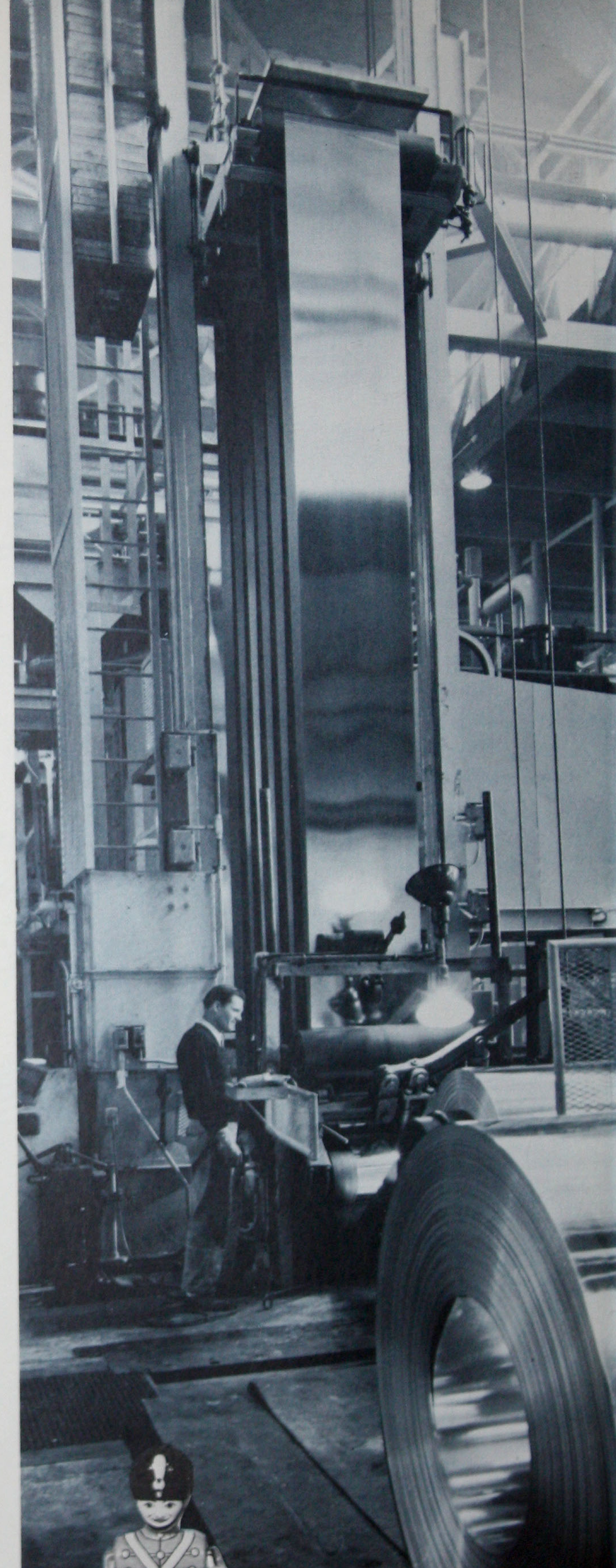
Cold working hardens steel, making it excessively stiff. The necessary softness and ductility are restored by *annealing*. The sheets or strip are placed in gas-fired annealing furnaces which are held at the proper temperature for a specified length of time. The steel is then removed and passed through a *skin-pass mill*, usually consisting of a single four-high stand. Skin-pass rolling reduces the thickness slightly, gives the steel a bright sheen, and restores just the correct amount of stiffness. Finally, the sheets or coils are inspected for proper finish, temper, gage and flatness.

Galvanized Sheets Have Many Uses

Large quantities of sheet steel are *galvanized*, coated with zinc for protection against rust or corrosion. Galvanized steel is used to make products such as water buckets, garbage cans, and rural mail boxes, for roofing and siding, and for ductwork in heating, ventilating and air-conditioning systems.

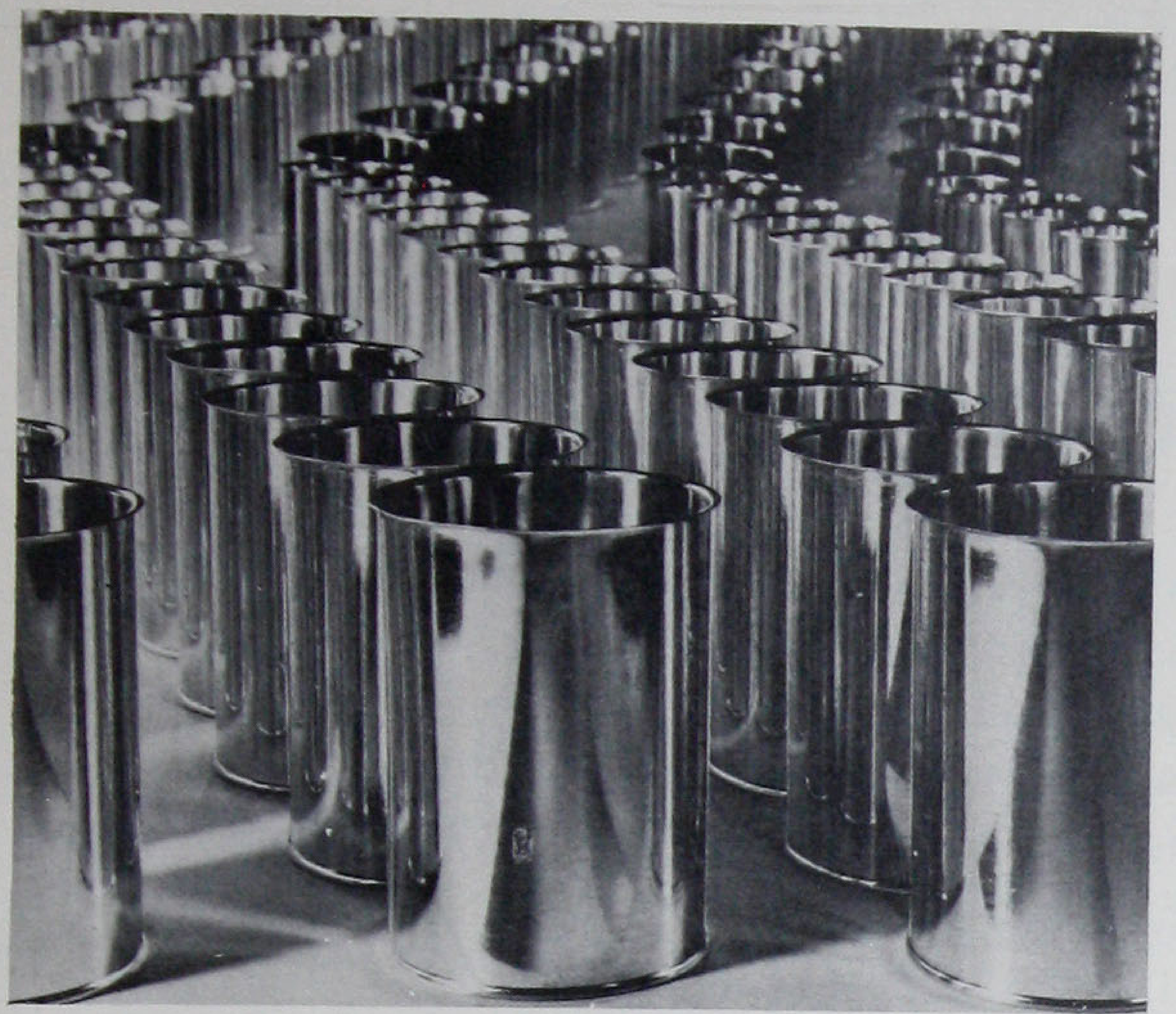
Heavier gages of galvanized sheets are made from hot-rolled sheets; lighter gages are made from sheets that have been cold-rolled as described above. Two methods of coating steel sheets and strip with zinc are in use today. In the *hot-dip process*, the zinc coating is applied by passing individual steel sheets through a bath of molten zinc. The other method, *continuous galvanizing*, is an extremely fast, efficient operation in which a long coil of strip is fed through the bath, then cut into sheets.

Steel is often galvanized for protection against corrosion.



Electrolytically coated strip leaving the plating line at Sparrows Point tin mill.

Many toys are made of tin-mill black plate.



So-called "tin cans," bottle caps and containers for candy, adhesive bandages, shoe polish and floor wax are made from tin plate.

Tin Plate

You can realize the importance of *tin plate* when you consider that about half of all the food we eat is packaged in cans made of tin plate. Many people are surprised to learn that so-called "tin cans" actually consist of almost 99 percent steel and only 1 or 1½ percent tin. The purpose of the light coating of tin on the outside and inside is to protect the steel from corrosion, and to impart an attractive, durable surface.

Preparing Steel for Tin-Plating

The first step in making tin plate is the preparation of extremely thin sheets and strip, called *tin-mill black plate*. This is done by cold-rolling as described in the preceding section, although slightly different equipment must be used in order to reduce the steel to the extreme thinness required for tin-plating.

An interesting sidelight is the fact that, due to its thin gage, tin-mill black plate is used in making Venetian blinds, toys and many other light articles.

Before the tin coating can be put on it, black plate must be perfect in two respects. First, it must be almost surgically clean. Second, it must be slightly etched so that the tin will readily adhere to its surface. These requirements are met by pickling the coils or sheets in a very dilute solution of sulphuric acid which removes any surface rust or specks of dirt, and lightly etches the metal.

Two Methods of Tin-Plating

Hot-dip tin-plating is the older method of producing tin plate. In this process, sheets of tin-mill black plate are fed automatically into rolls which guide the sheets through a pot of molten tin and up through a pot of palm oil containing rolls which control the thickness of the tin coating and distribute the tin evenly over the sheets. The coated sheets pass through a stream of bran which takes off the excess oil, and are finally polished by cloth-covered rolls revolving in finely-powdered bran.

The sheets of tin plate are then taken to a well-lighted room where they are carefully inspected before shipment. The slightest imperfection results in a rejected sheet.

Electrolytic tin-plating, like many other technical advances, was developed under the pressure of wartime necessity. During World War II there was a shortage of tin. As a much lighter coating can be applied electrolytically than by the hot-dip method, the electrolytic process was developed to conserve the available tin supply. However, certain heavy coatings can also be applied economically by this process.

Electrolytic tinning, which is faster and more efficient than the hot-dip method, is a continuous process. Long coils of prepared tin-mill black plate are fed through an electrolytic bath, in which a uniform coating of tin is deposited on the steel by the action of an electric current. The gleaming steel strip speeds through the bath at 450 to 1200 feet per minute, then passes through a furnace. The heat melts the tin which flows, forming a lustrous coat. From the electrolytic line, the strip is carried to rotary shears which cut it into sheets. These sheets must pass both an electric-eye and an expert visual inspection.

Structural Shapes

The dominant building material of the Twentieth Century is the *structural steel shape.* Structural shapes and, in particular, the *wide-flange* shapes which were first produced in America by Bethlehem in 1907, made possible the skyscrapers of modern America. Many of the towering buildings and bridges that are the construction marvels of our time derive their strength from sturdy structural steel shapes.

Rolling Structural Steel

Structural steel is produced in a number of *standard sections:* I-beams, channels, angles, tees and zees. They are made by passing steel blooms between grooved rolls, the action of the rolls squeezing the hot plastic steel into the grooves. In this way the bloom is altered a little more from its original shape on each pass until, passing through the final grooved rolls, it emerges with the desired shape and size.

It is obviously no simple matter to change the cross-sectional shape and area of a large, square bloom into an I-beam. The process may require as many as twenty-six roll passes. The first few passes are chiefly designed to reduce the bulk of the bloom. Succeeding passes gradually form the blank into the final shape.

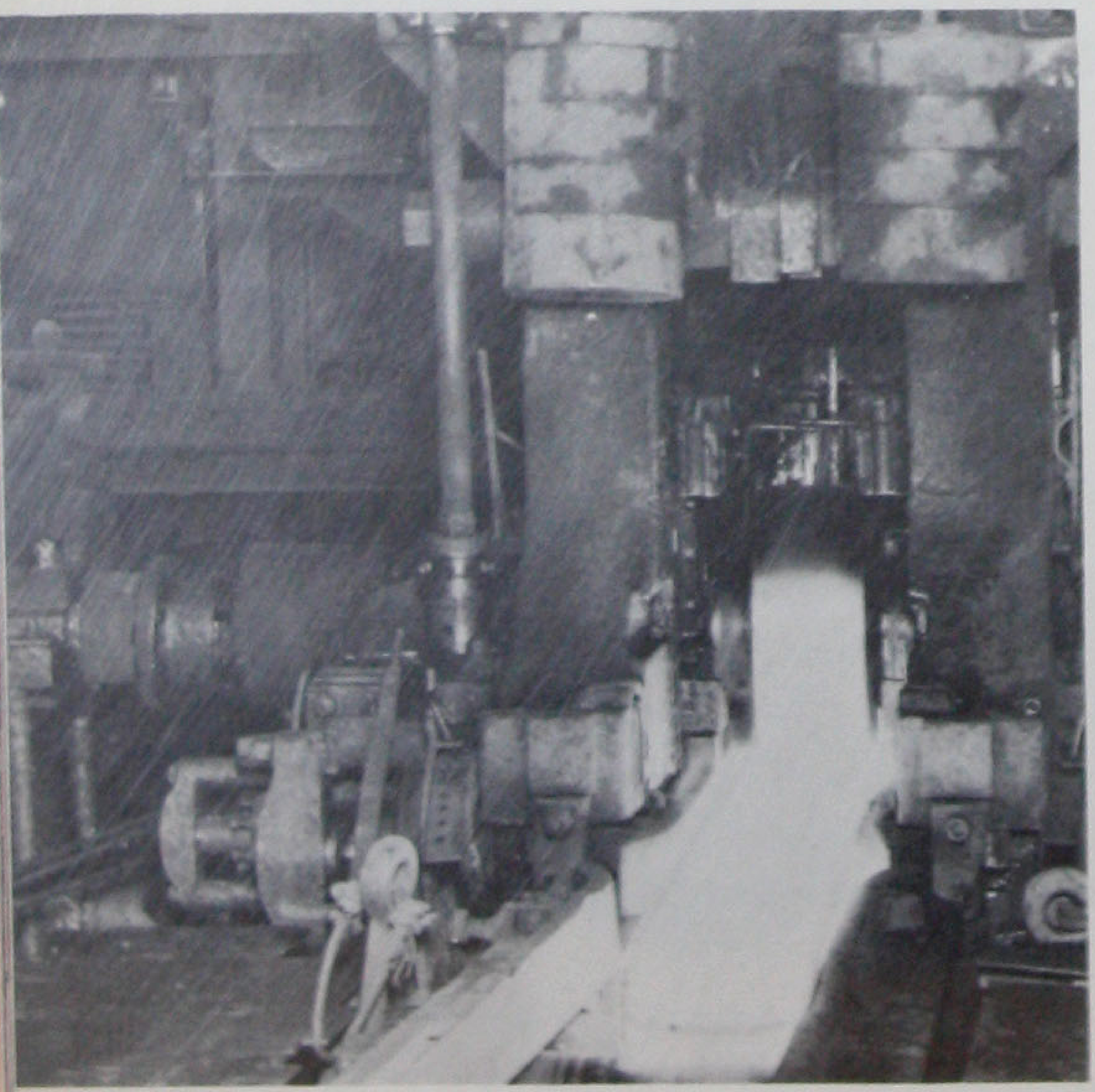
While standard structural shapes are formed on mills with grooved horizontal rolls, wide-flange shapes are rolled on special reversible mills known at Bethlehem as *Grey mills.* Instead of grooved rolls, which it is not feasible to use for rolling shapes with wide flanges, Grey mills have smooth, relatively narrow horizontal and vertical rolls which may be spread or closed between passes. The horizontal rolls work on the center portion or *web* of the beam between the flanges and on the inside faces of the flanges. The vertical rolls work on the outside faces of the flanges only.

After they have been rolled to the desired cross-section, structural shapes are straightened and cut to length.

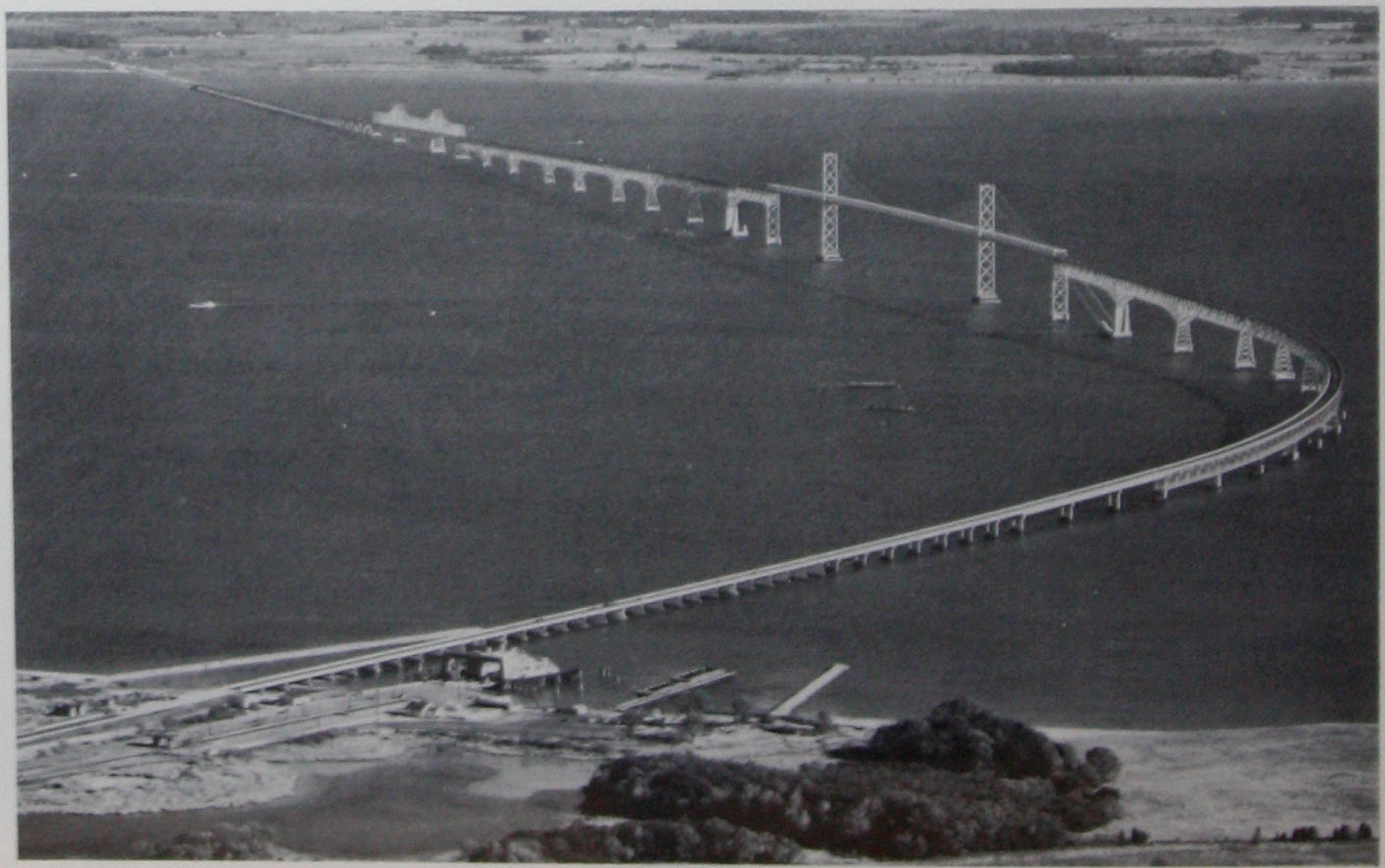
Fabricating and Erecting Steel Structures

Bethlehem not only produces structural steel shapes, but also fabricates and erects steel structures of all types. The steel frameworks of many of America's landmarks — the Golden Gate, Chesapeake Bay and George Washington bridges, New York's Waldorf-Astoria Hotel and Chicago's Merchandise Mart — were fabricated and erected by Bethlehem's Fabricated Steel Construction Division.

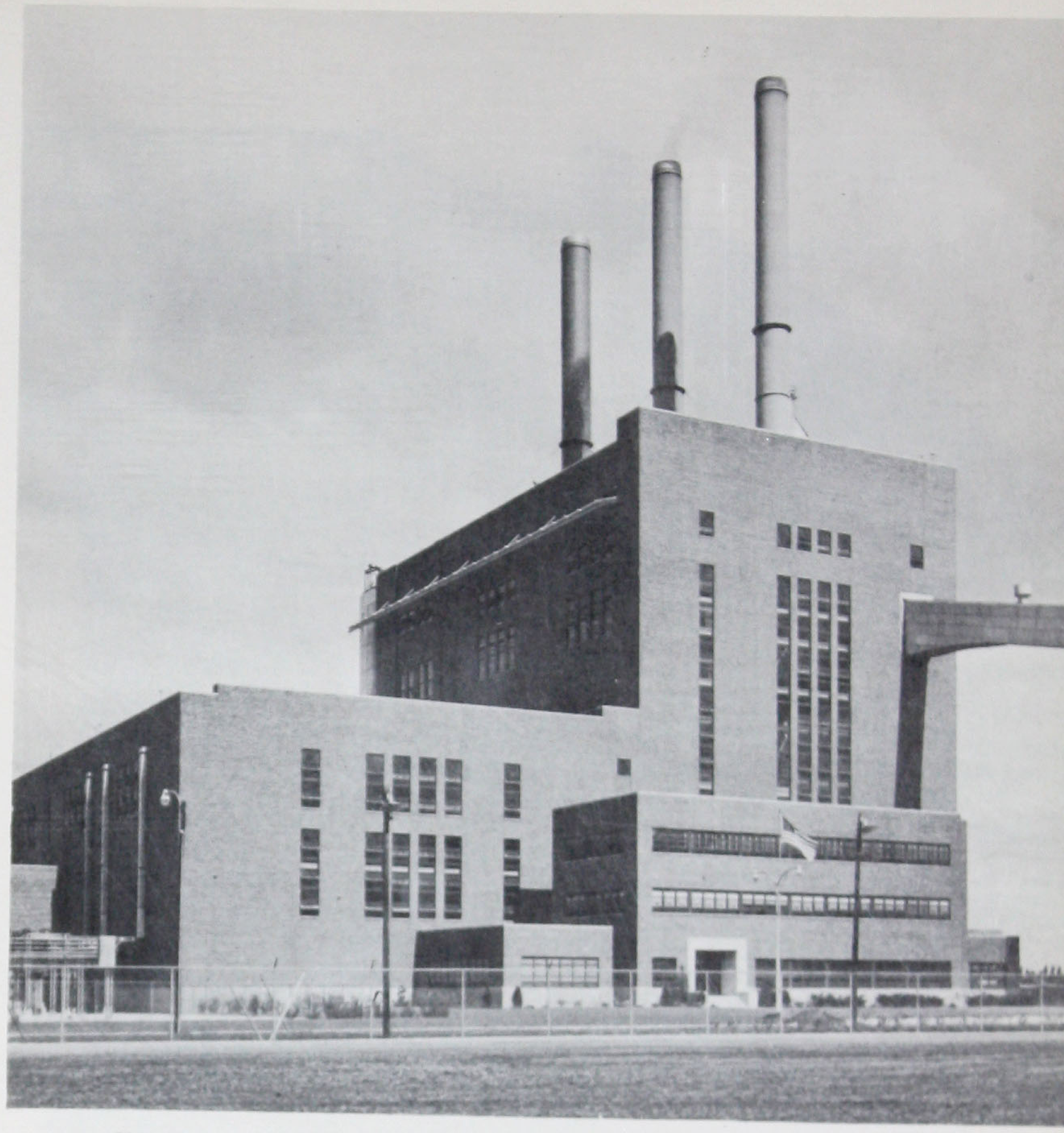
Rolling a wide-flange structural beam on a Grey mill at the Bethlehem Plant. The smooth, narrow horizontal and vertical rolls are visible.



The 4-mile-long Chesapeake Bay Bridge near Baltimore, opened for traffic in 1952, is the third longest bridge in the world, and the first to span Chesapeake Bay. The superstructure of 30,000 tons of structural steel was fabricated and erected by Bethlehem.



Bethlehem fabricated and erected John Hancock Mutual Life Insurance Company's handsome home office in Boston, Mass. It is twenty-nine stories high and contains 14,700 tons of structural steel.

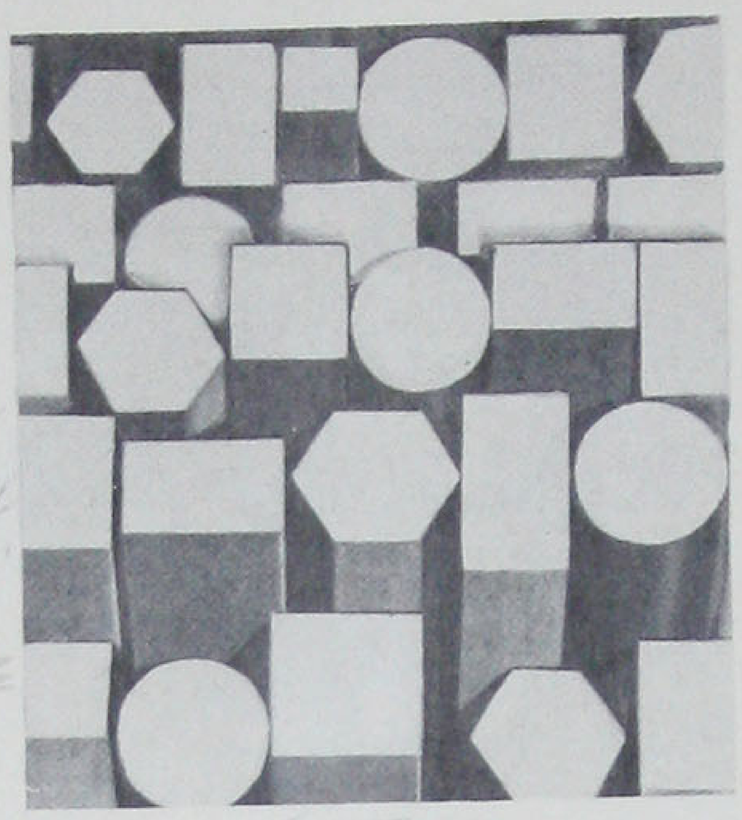


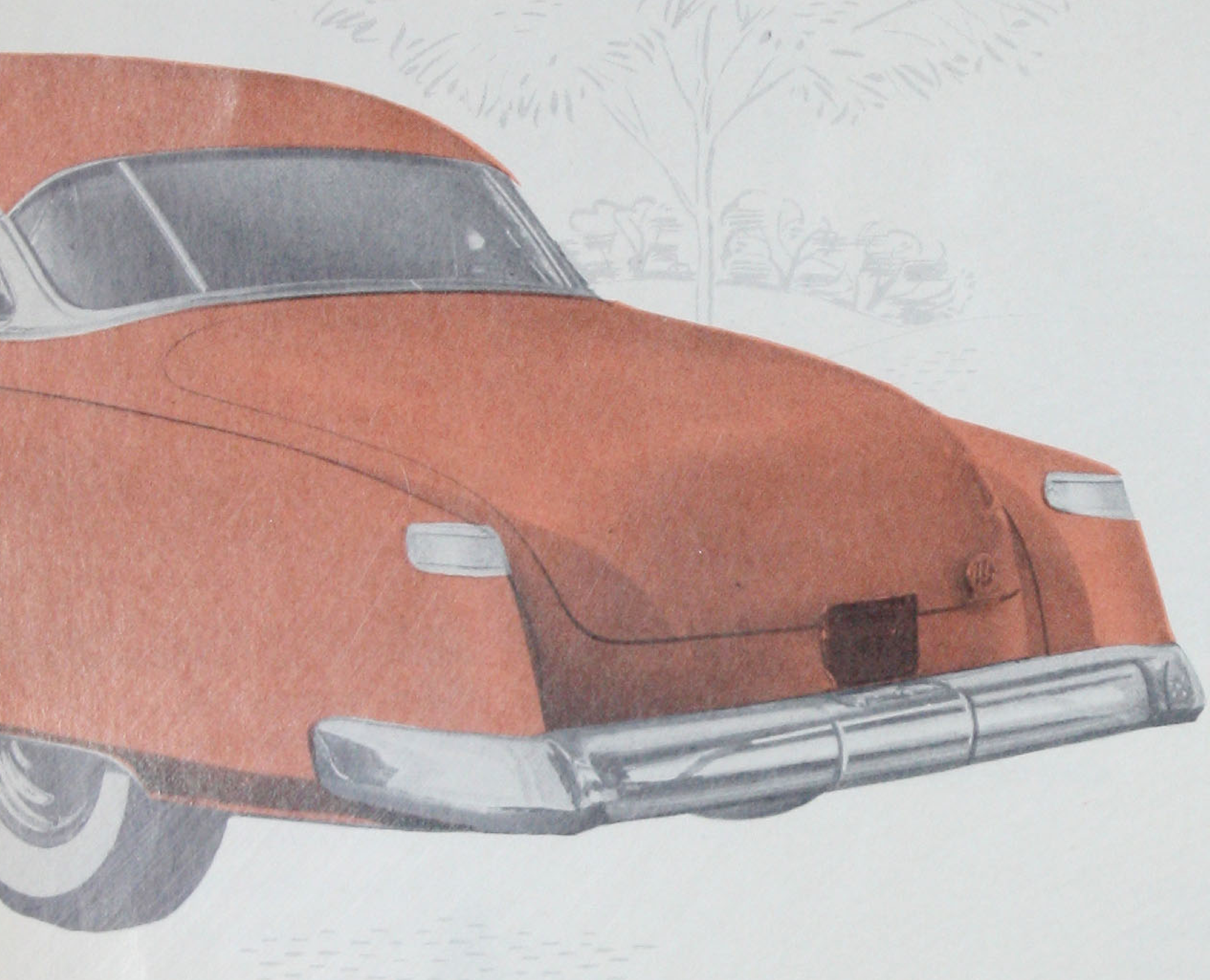
This is a new power plant on Lake Erie near Detroit, Mich. Its main boiler room is about as high as a 16-story building. Bethlehem supplied the structural shapes for the framework of this huge structure.

The 43-story Waldorf-Astoria in New York City has a framework of 25,000 tons of Bethlehem structural steel. Bethlehem also fabricated and erected the steel for this monumental building.

A striking building in a glittering setting, this department store in Beverly Hills, Calif., was fabricated and erected by Bethlehem Pacific. Structural steel often makes possible such modern design.

Bars





The important role of *steel bars* is brought home by the fact that over 600 pounds of bar steel go into the average passenger automobile. Crankshafts, connecting rods, spark plugs, axles, tire rims, door hinges and many other vital parts are formed from various grades of carbon or alloy-steel bars, or special shapes rolled as bars. The average farm tractor contains 900 pounds of steel bars; the average diesel locomotive, over 17,000 pounds. Many everyday hand tools — knives, axes, hammers, pliers and wrenches — and various parts of every type of power-driven machinery are made from steel bars. In addition, many thousands of tons of reinforcing bars are used every year in the construction of concrete buildings, highways and bridges.

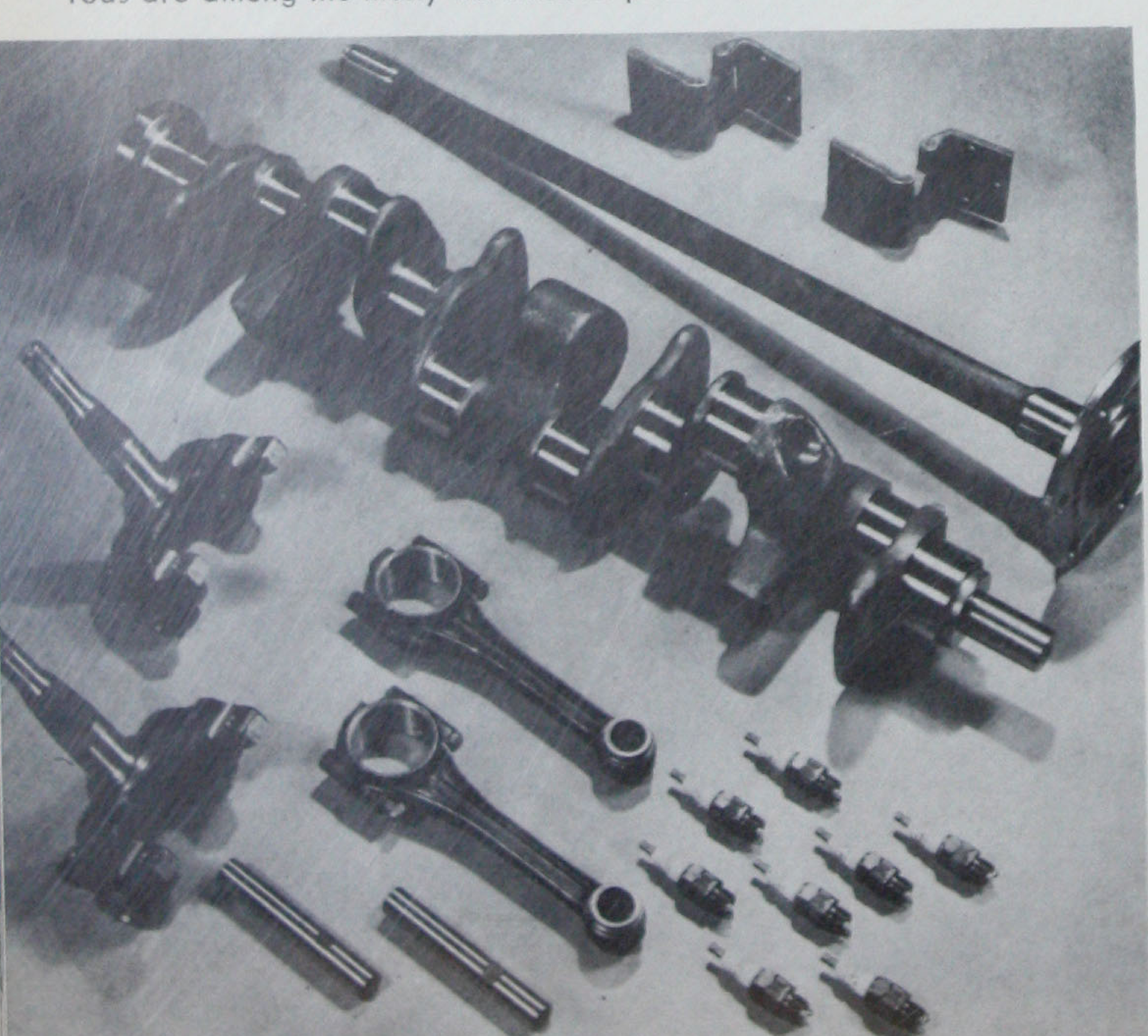
Steel bars come in many different shapes, the most common ones being round, square, hexagonal, octagonal, half-round, oval and flat.

Bars Are Rolled on Merchant Mills

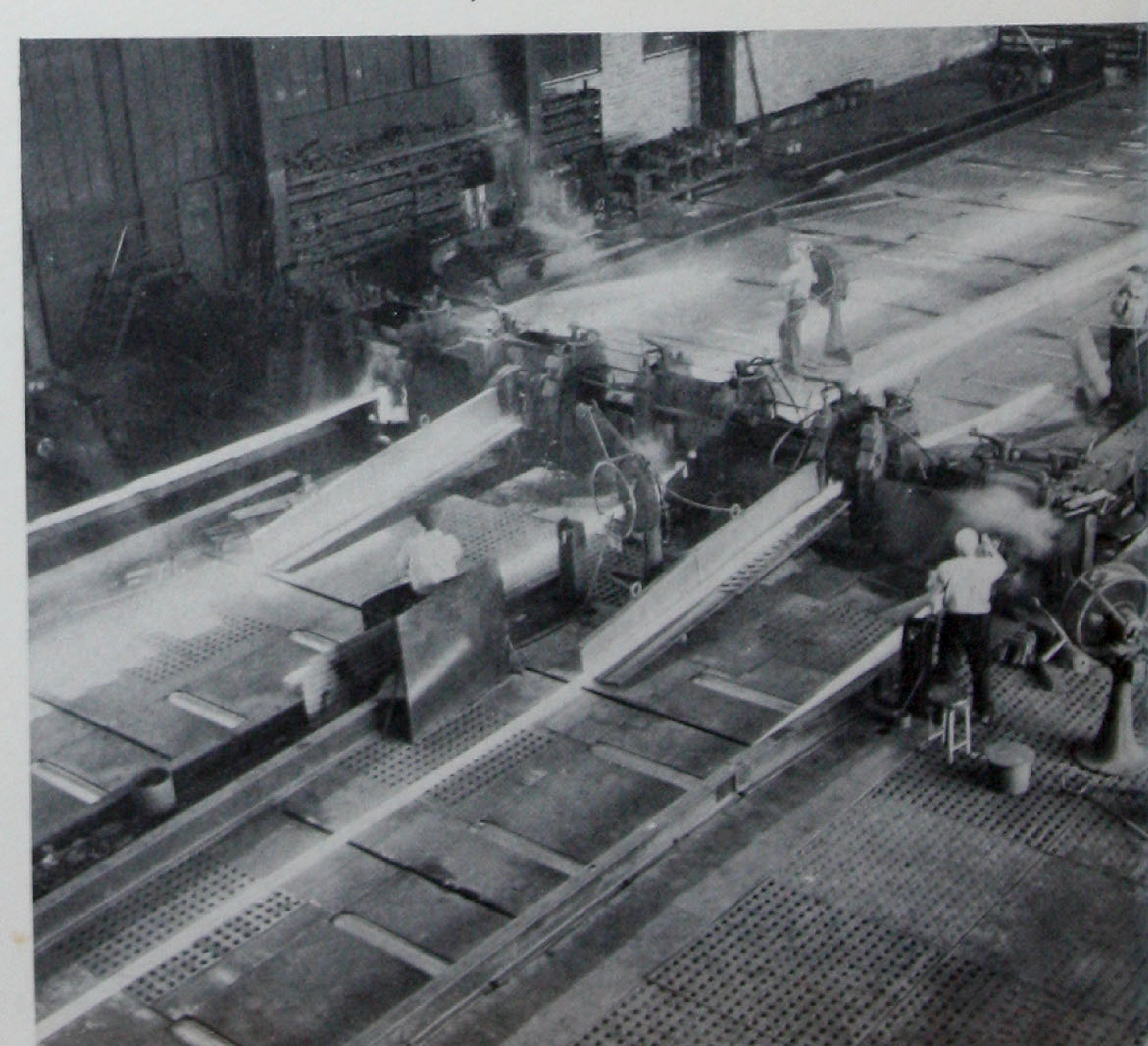
There are many types of bar mills, all of which are commonly called *merchant mills.* They vary from the highly mechanized continuous bar mill to the hand mill, where workmen use long-handled tongs to guide the steel through the rolls.

Continuous mills, having great productive capacity, are used to produce high tonnage products — the simple *standard bar sections,* which include reinforcing bars.

Spark plugs, crankshafts, camshafts, valve lifters and connecting rods are among the many automobile parts made from steel bars.



Rolling bars from billets on a bar mill at the Los Angeles Plant. The entire operation takes less than two minutes.



Other types of mills are not as fast but are more flexible, and are generally used to produce the more complex *special bar sections.*

From Billet to Bar in 2 Minutes

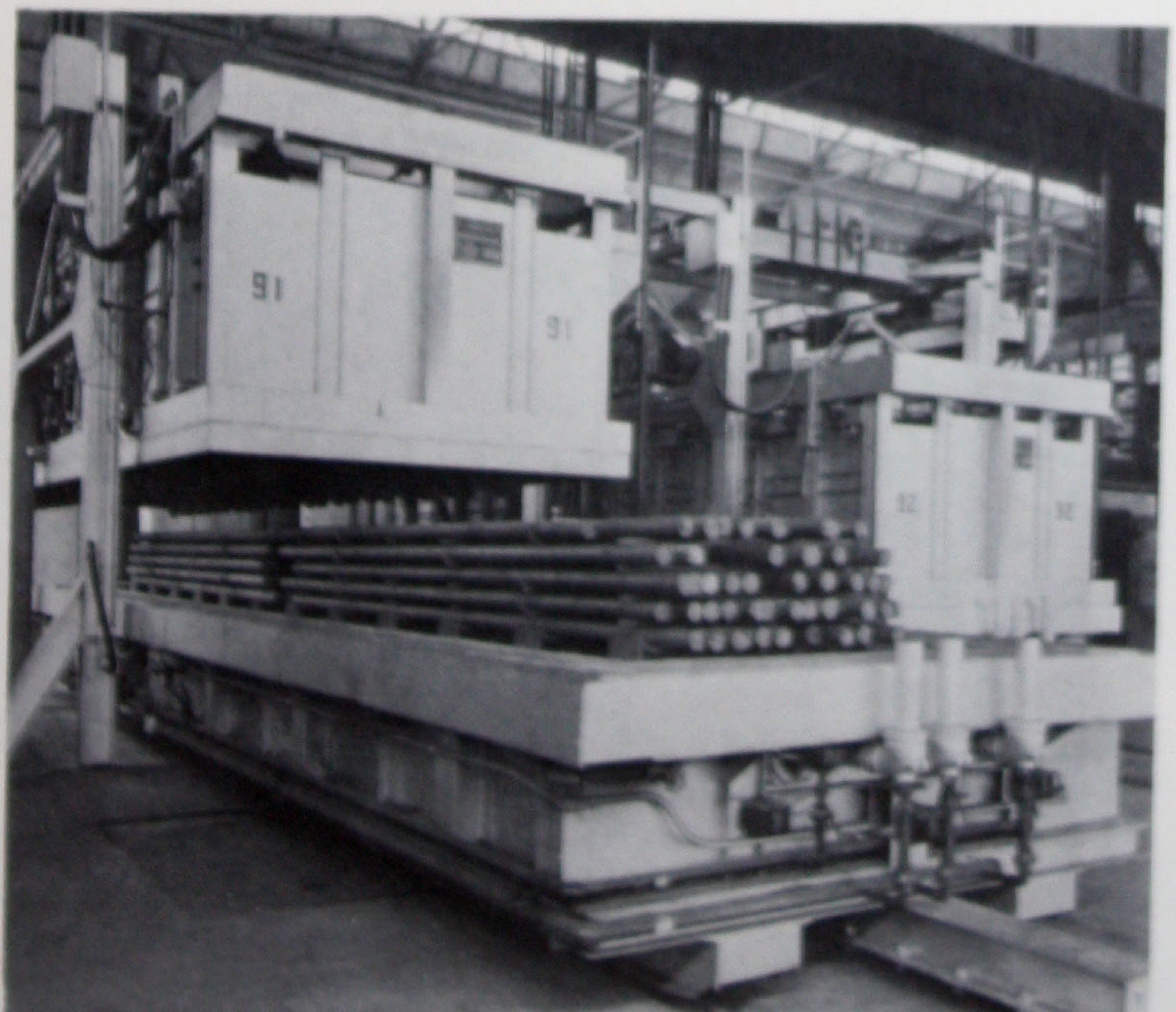
In a modern high-speed continuous bar mill, the hot billet, between 4 and 6 inches square in cross-section and from 16 to 30 feet long, leaves the furnace and enters the roughing train. Growing steadily slimmer and longer, and accelerating to a top speed of almost 30 miles an hour, the steel flashes to the cooling beds in the shape of a long finished bar. The entire process, from heating furnace to cooling bed, usually takes less than two minutes.

The processing after cooling varies considerably, according to the type of bars rolled, and may include straightening, cutting to specified lengths, heat-treating, grinding and polishing, bending or other deforming operations. A large part of the total bar output serves as the raw material for cold-drawing, forging, upsetting, machining or other operations.

Cold-Drawn Bars

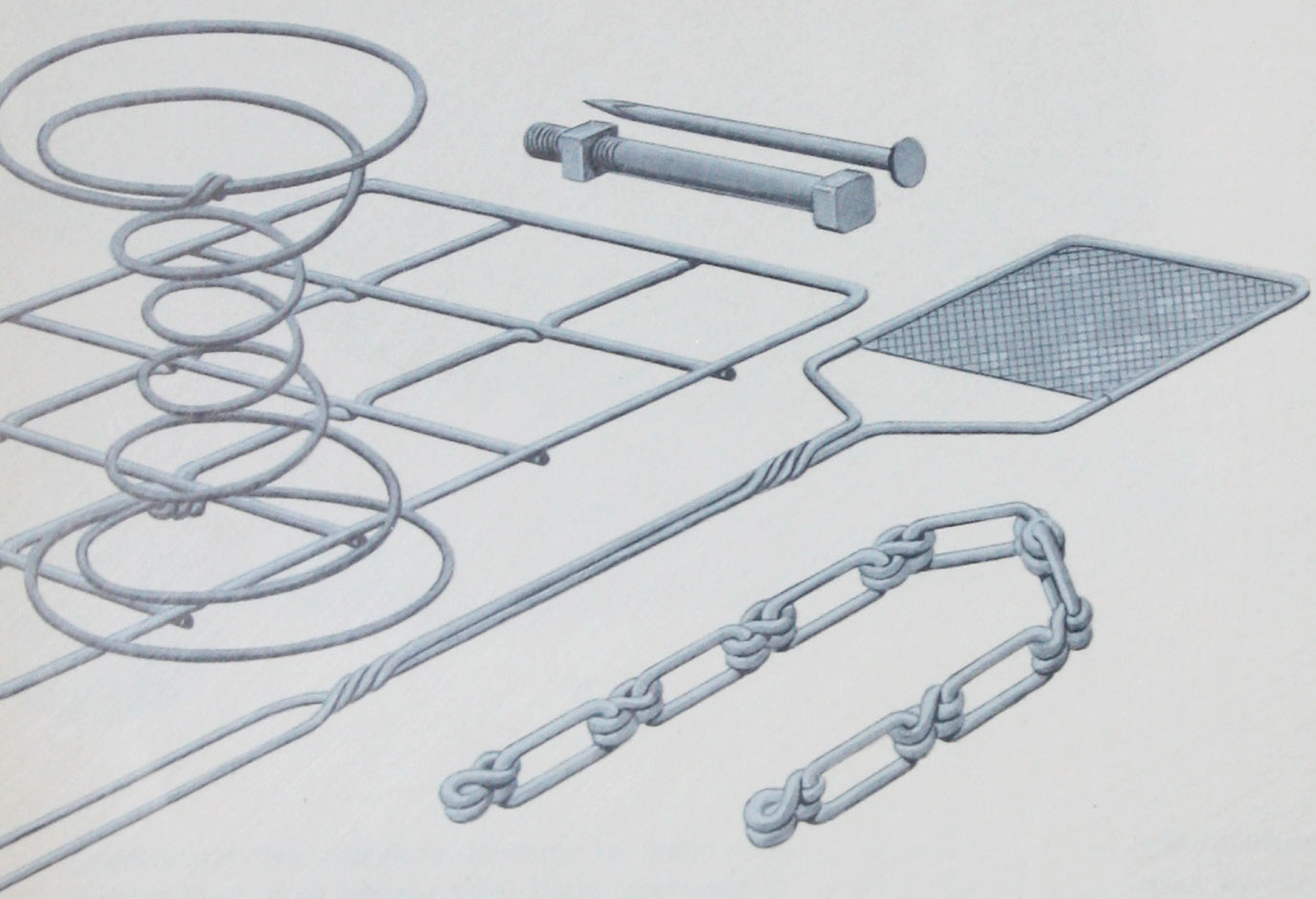
A considerable tonnage of hot-rolled bars are cold-drawn through dies in an operation rather similar to wire-drawing. This process makes the steel stronger, imparts a smooth, bright surface, finishes it to more exact dimensions, and greatly improves its machinability.

Certain properties of hot-rolled bars, such as ductility and machinability, are improved by annealing in furnaces such as the one shown here.



Assortment of common wrenches, representative of the many hand tools forged from steel bars.

Rod and Wire Products



Steel wire is one of the most versatile and most widely used of all steel products. It has thousands of applications, including innumerable products that we use every day. Fasteners of all sorts, from spikes to staples, nails, screws, paper clips, pins, tacks and many types and sizes of bolts are made from steel wire. Springs for machinery and for furniture, farm fences, mesh for screen doors, bicycle spokes, coat hangers, chains, piano wires and kitchen utensils — all are made from steel wire.

All steel wire is cold-drawn from hot-rolled rod. Rod, in turn, is rolled from billets, generally between 1¾ and 3 inches square in cross-section, and about 30 feet long. Depending on the design of the mill being used, from two to four billets producing an equal number of strands of rod may be rolled simultaneously, side by side.

Rolling Rod from Billets

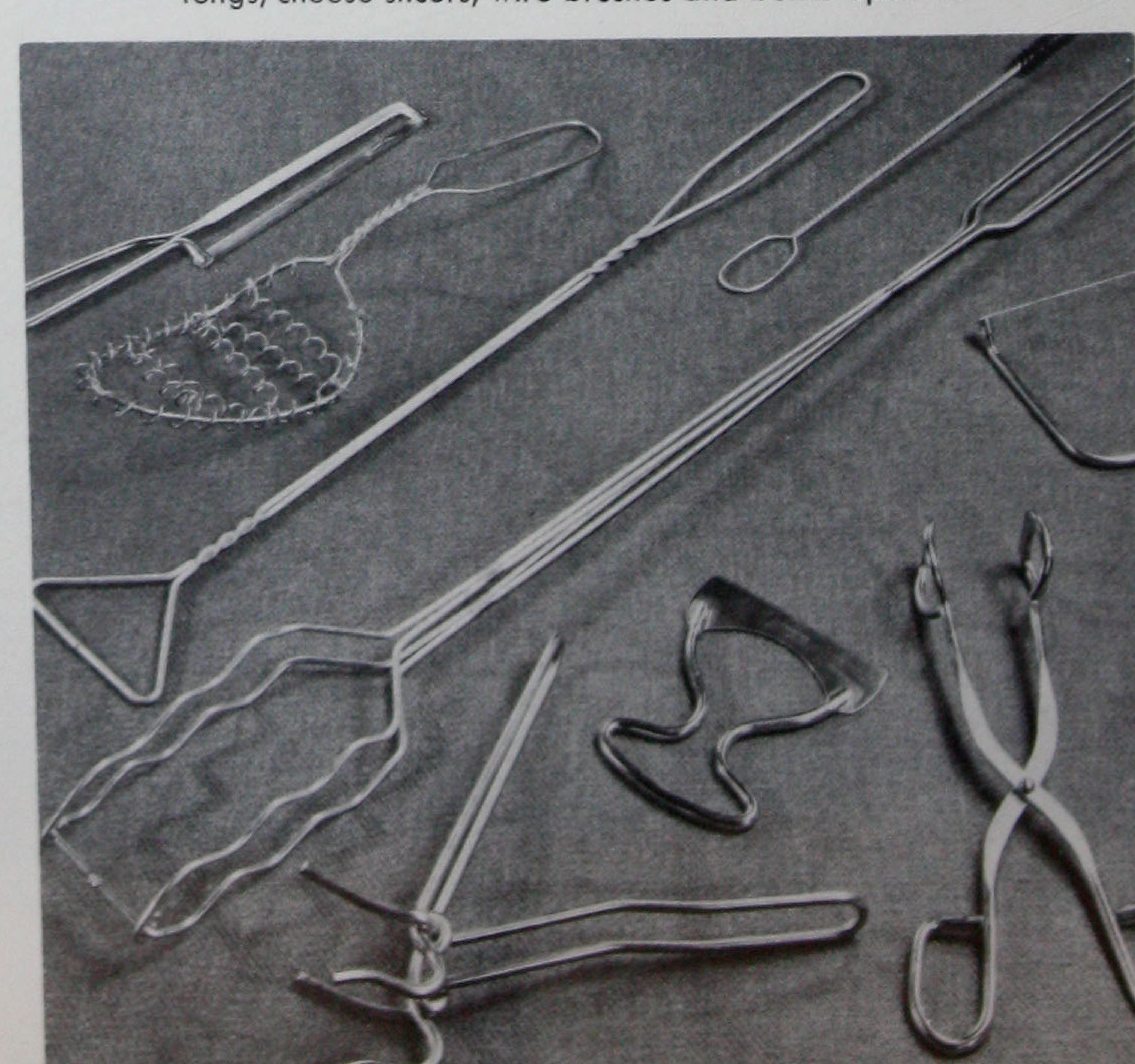
These billets are uniformly heated to the proper rolling temperature in a special furnace, then fed into a *continuous rod mill.* Continuous rod mills of the most modern type generally consist of two main sections — a set of roughing stands and a set of finishing stands. The total number of stands is usually over sixteen.

As they enter the "bite" of the first roughing stand, the billets are traveling at about 10 miles an hour. They pass from stand to stand, growing thinner and longer — and therefore moving faster — at each pass, until the finished rod speeds from the last finishing stand at between 40 and 50 miles an hour. The rod is then quickly coiled.

During the hot-rolling process a 30-foot-long billet may be lengthened to nearly a mile. The whole operation takes

Thousands of miles of farm fence and barbed wire are made from steel wire every year.

Housewives use many utensils made of steel wire— tongs, cheese slicers, wire brushes and bottle openers.



just a little over one minute. Concrete reinforcing bars, as well as rods, are turned out by some rod mills.

Wire is made by pulling rod through tapered holes or *dies* slightly smaller in diameter than the rod itself. In this way the diameter of the rod is decreased while the length is increased. The usual arrangement is to draw the rod through a series of successively smaller dies, until the finished wire is of the desired diameter.

Drawing Wire from Rod

In preparing rod for wire-drawing, the first step is to remove the oxide scale which forms after hot-rolling. This is done by pickling the coiled rod in hot dilute sulphuric acid. When the scale has been removed, the rod is bathed in water which washes away the acid. Next, the rod is dipped in a lime solution, then is baked in an oven to "fix" the lime coating. This coating serves as a base for the lubricant that eases the rod through the dies.

The prepared coil is placed on a reel at the wire-drawing machine, the end of the rod is pointed and started through the tapered die. These dies are made of hard, rigid substances, much harder than the rod itself.

After passing through the die, the rod is passed around a power-driven drum or *block*. As this block revolves, it pulls the rod through the die. In continuous wire-drawing, the rod is drawn through a series of dies and around a series of blocks.

Continuous wire-drawing is similar to continuous rolling, in that the steel is gradually reduced in cross section and its length proportionately increased. Therefore, as the wire moves along from die to die each succeeding drum must rotate faster to accommodate the lengthening wire. On leaving the last die the smaller sizes of wire may travel as fast as 20 miles an hour.

Heat-Treating Restores Ductility

The tremendous strain of cold-drawing hardens the steel to the point where it cannot be drawn any further. The wire's softness and capacity for cold-working is restored by annealing the wire during intermediate stages of drawing and after final drawing.

Another important operation in the production of steel wire is *patenting*. This is a special heating process which is used to prepare wire rod of high carbon content for drawing, and also to condition the wire at intermediate stages during the drawing operation. Patenting consists of passing the rod or wire through a long furnace, then cooling the steel rapidly in air or in a bath of molten lead.

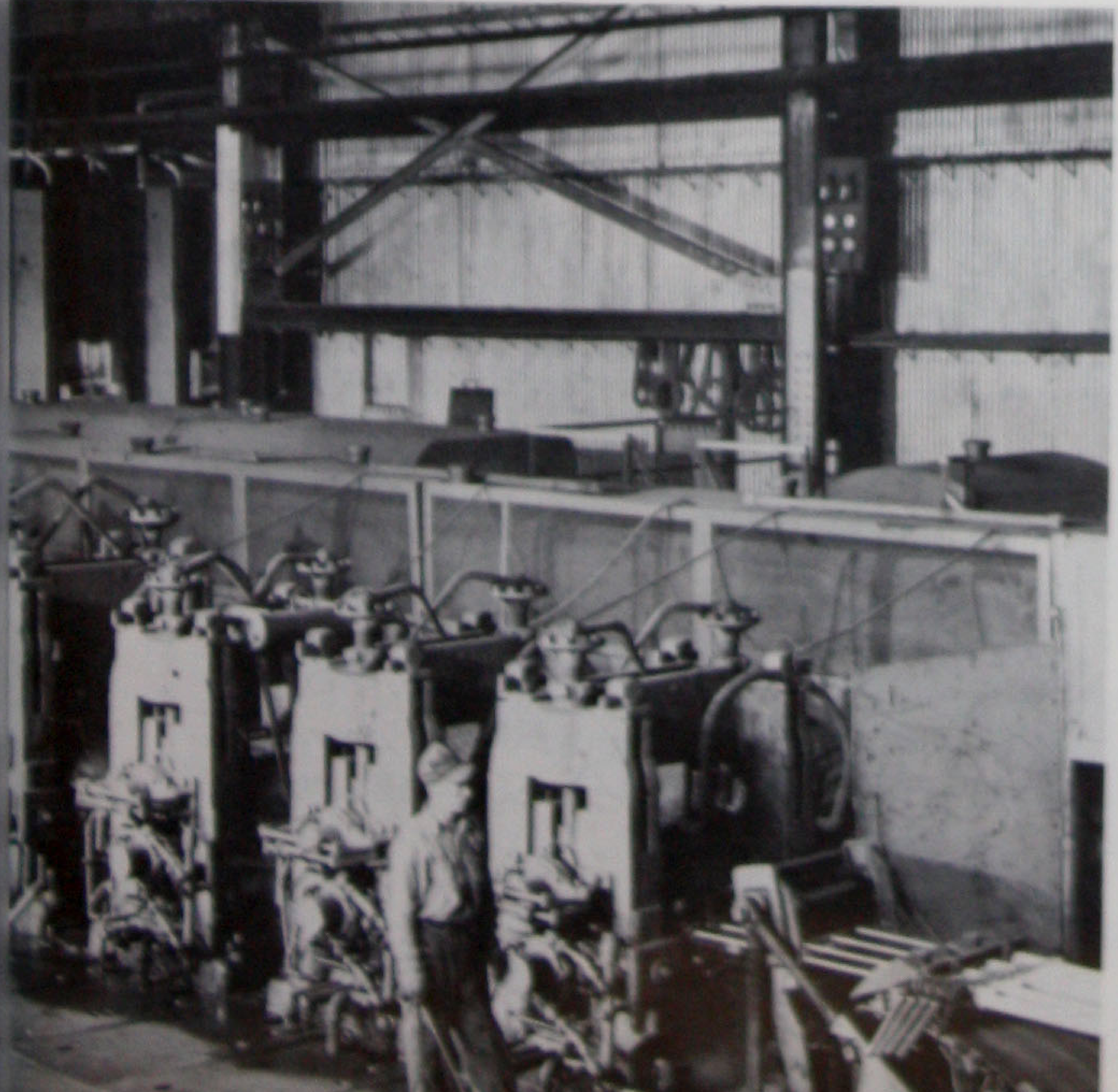
Two Methods of Zinc-Coating Wire

A great deal of wire is galvanized, that is, it is coated with zinc to prevent rust or corrosion. Bethlehem uses two zinc-coating methods: the *hot-dip* process and the *bethanizing* process.

In the hot-dip process, annealed and cleaned wire is passed through a bath of molten zinc, often many strands at a time.

In the bethanizing process, the wire is electrolytically cleaned and pure zinc is deposited uniformly on the wire as it passes through an electrolytic bath. This process produces a more ductile and more firmly bonded coating than the hot-dip process.

This view of a continuous rod mill shows the simultaneous rolling of four strands.



Battery of modern wire-drawing machines. Rod enters at the left, is reduced in size as it passes through successive dies, and is coiled at the right.

Laying a natural gas line of electrically welded steel pipe. This pipe is also used to carry gasoline, crude oil, water and sewage.

Tubular Products

Tubular products—pipe and tubes—are either welded or seamless. *Welded pipe* is made by forming flat steel into cylindrical shape and welding the edges together in a long welded seam. *Seamless tubing* is made by piercing solid bars and billets, and therefore has no weld seam.

Steel pipe is made in diameters ranging from fractions of an inch up to 12 feet or more. The smaller sizes are extensively used in plumbing and heating systems, and in countless industrial applications. The large sizes are used mostly in cross-country pipe lines for oil and gas, and in water and sewage systems.

Steel tubing, due to its lightness and strength, in addition to carrying gases and liquids is widely used for structural purposes. Bicycle frames, flag poles, airplane bodies, furniture and playground equipment, are among the many structural applications of steel tubing.

Continuous Butt-Welding

Welded pipes and tubes are made by three methods: *continuous butt-welding*, *lap-welding* and *electric welding*. Seamless pipes and tubes are made by the piercing process described later.

Welded pipe from ½ inch to about 4 inches in diameter is usually made on the *continuous pipe mill.* Steel in the form of long strips, called *skelp*, is fed into a furnace where it is heated to the welding temperature. The skelp then moves through a series of roll-passes, consisting of multiple pairs of horizontal and vertical rolls. The rolls form the moving skelp into a cylinder, welding together the heated edges.

As the pipe leaves the rolls, a saw cuts it into lengths. After it has cooled, the pipe is straightened and threaded. The strength of the weld is tested *hydrostatically*, by sealing the ends of the pipe and pumping in water under high pressure. Pipe is often galvanized, by coating it with zinc, to protect it from corrosion.

Lap-Welding

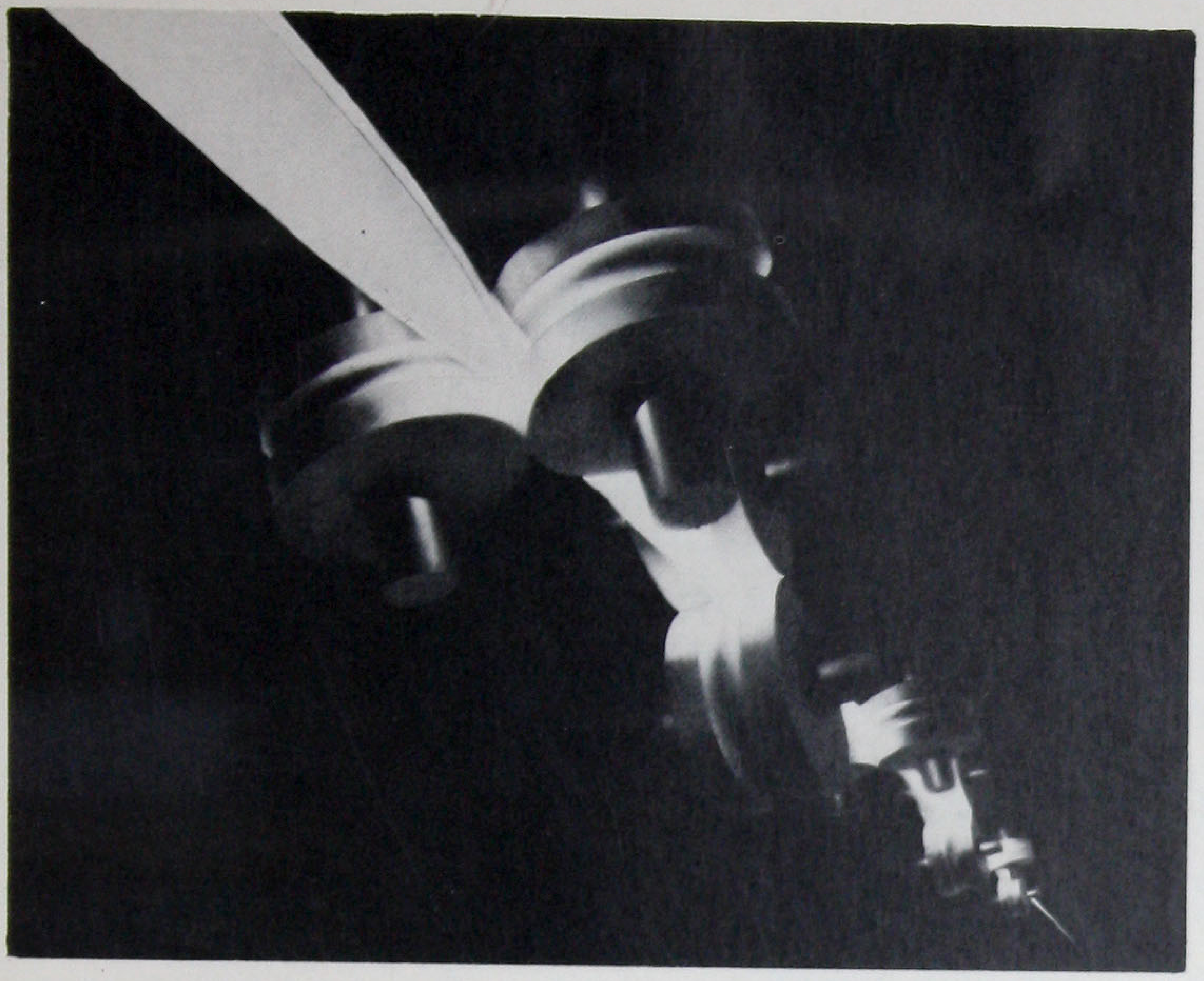
Pipe between 4 and 16 inches in diameter is made by *lap-welding.* Lengths of skelp are heated, the edges are beveled, and the skelp bent into a cylinder with overlapping edges. This bent skelp is then reheated to welding temperature and drawn over a welding ball held between two rolls. As the hot skelp passes over the ball, the rolls press the lapped edges against it, automatically welding the edges together.

After welding, the pipe passes through a set of sizing rolls. Then it is straightened, allowed to cool, threaded and hydrostatically tested.

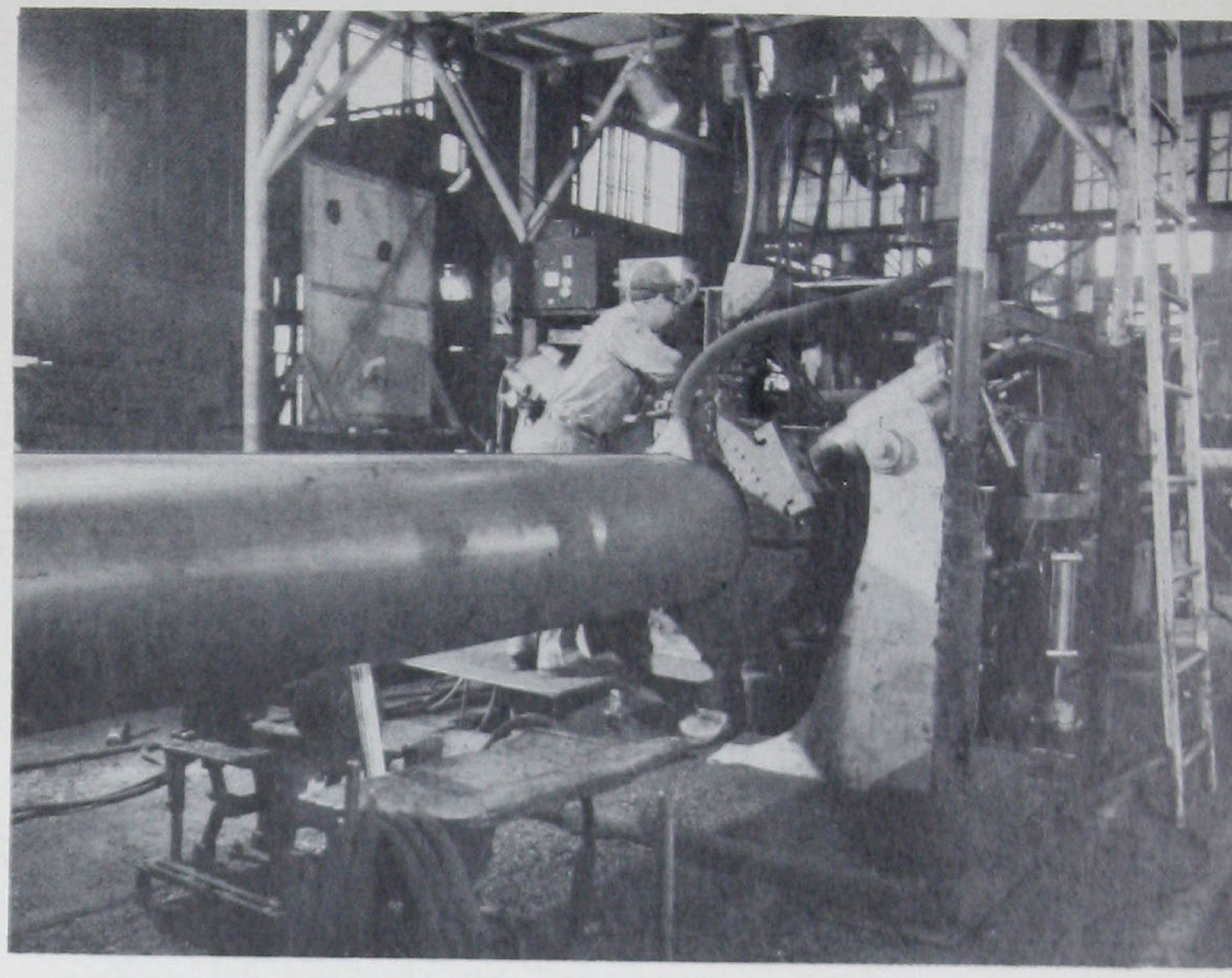
Electric Welding

Electric-weld pipe is made in sizes up to 150 inches in diameter or more, the upper limit being governed by shipping clearances rather than manufacturing limitations. The large-diameter steel pipe used to carry oil, gas and water long distances is made by electric welding.

Electric-weld pipe is made from plates, usually 20, 30



Small-diameter pipe is formed by continuous butt-welding. Skelp is welded into pipe as it passes through sets of rolls.

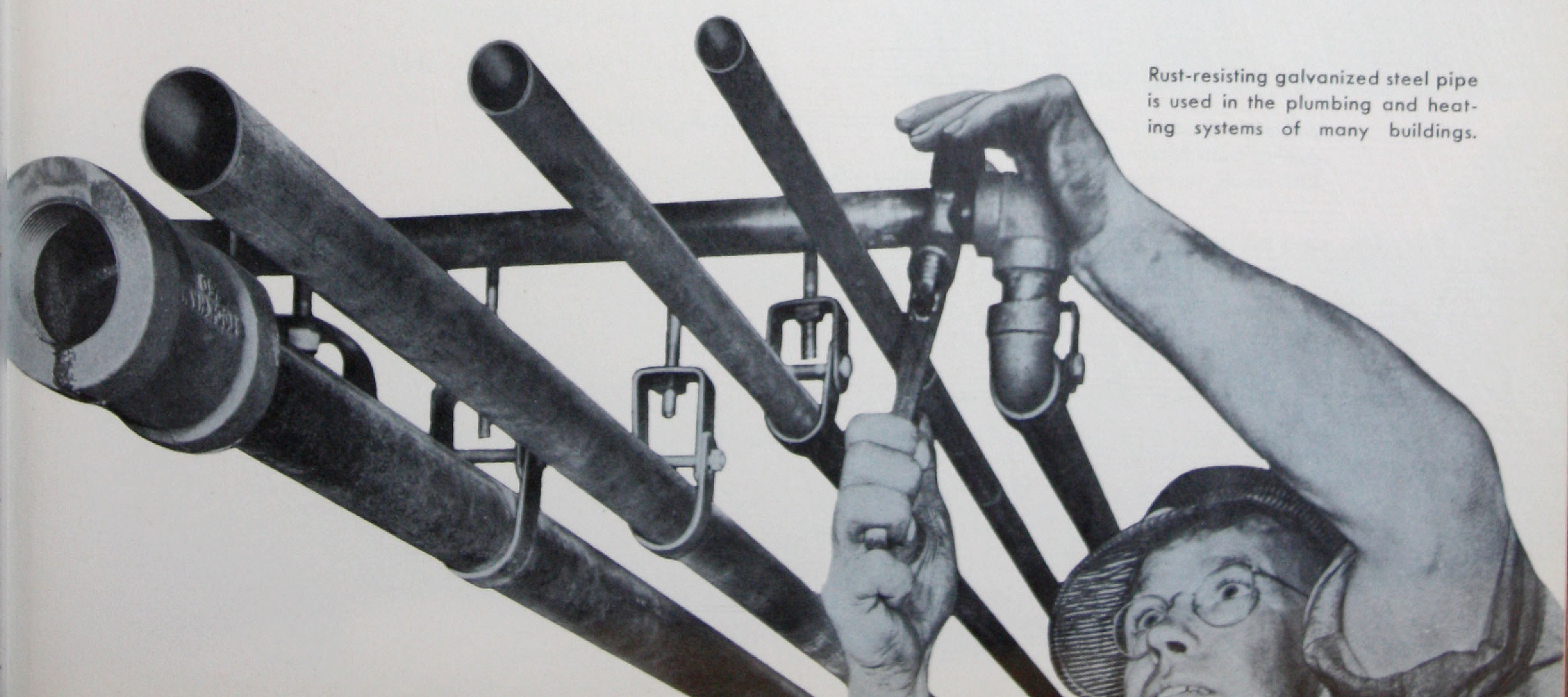


Curved steel plates are fed into this electric welding machine which welds the edges together, forming large-diameter steel pipe.

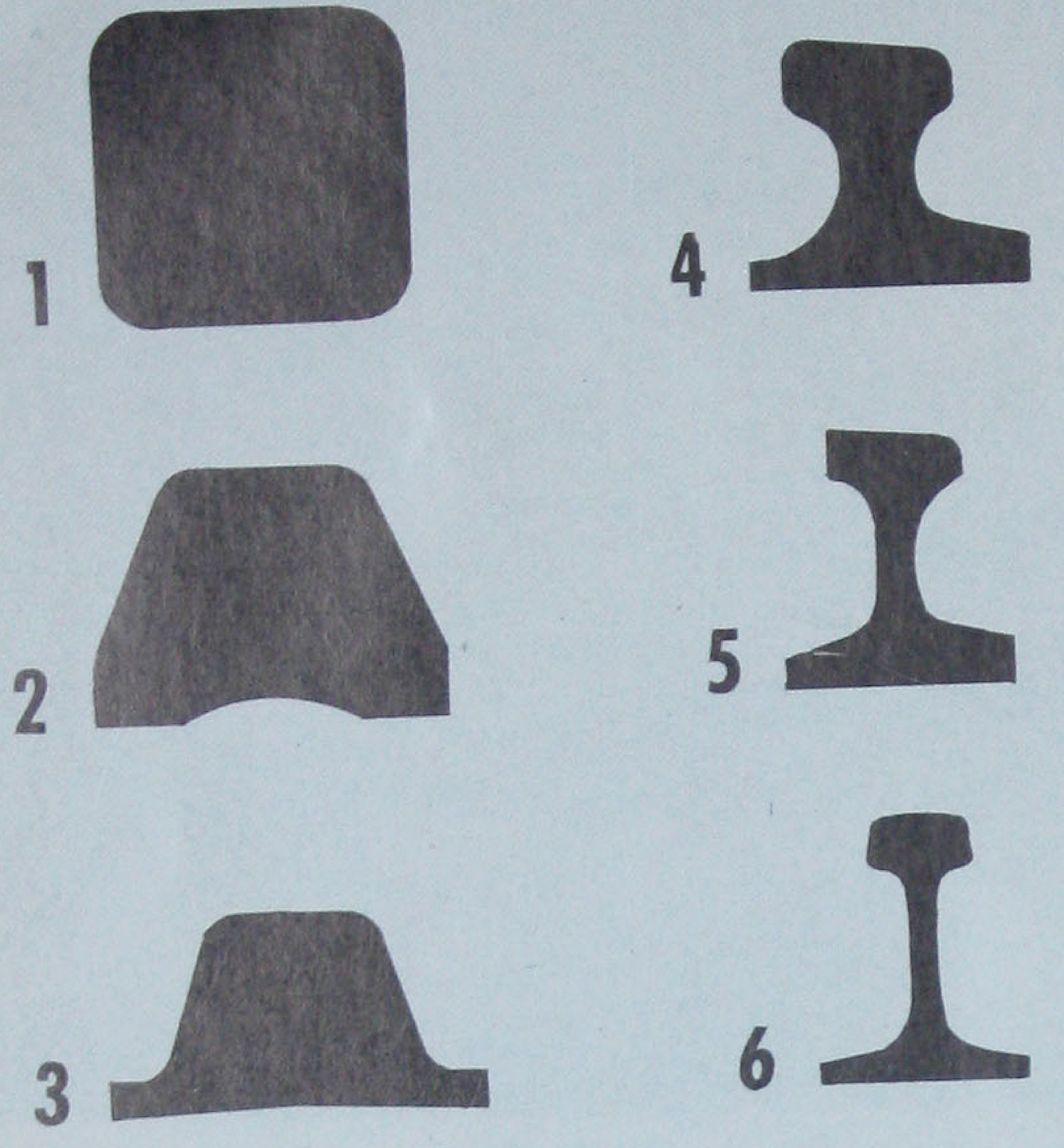
or 40 feet long and often over 1 inch thick. First, all four edges of the plate are planed in order to assure a tight joint when welded. The long edges are crimped, then powerful rolls bend the plate into cylindrical shape. The formed plate, held in shape by temporary or "tack" welds, is then welded on a large electric-fusion welding machine. A hydrostatic test insures the strength of the weld and freedom from leaks.

Making Seamless Tubing

Seamless pipe and tubing is made from *tube rounds*, a form of semi-finished steel, by a number of methods. In one of these processes a tube round, preheated to a uniform working temperature, passes between a pair of rotating crossed rolls. The rotating action of the rolls forces one end of the round against a piercing plug or mandrel. The combined rolling action and the pressure of the rolls tends to open the round at its center. The mandrel controls and completes this piercing action. The result is a rough tube which is then finished by passing it through a set of rolls over a ball in a process similar to the finish-rolling of lap-welded pipe. Various ingenious procedures make it possible accurately to control the wall thickness and the outside diameter of the tubing.



Rust-resisting galvanized steel pipe is used in the plumbing and heating systems of many buildings.



A few of the steps in rolling rails. These simplified diagrams illustrate how a bloom is gradually shaped into a rail by the action of the rolls.

Rails

Steel rails for America's railroads were first made in this country in 1867 at what is now Bethlehem's Johnstown, Pa., Plant. Today, rails remain one of the most important of all finished steel products. The safety of millions of travelers depends on the quality of these rails. Rails have to stand up under fast, heavy trains and endure the strains caused by severe weather conditions.

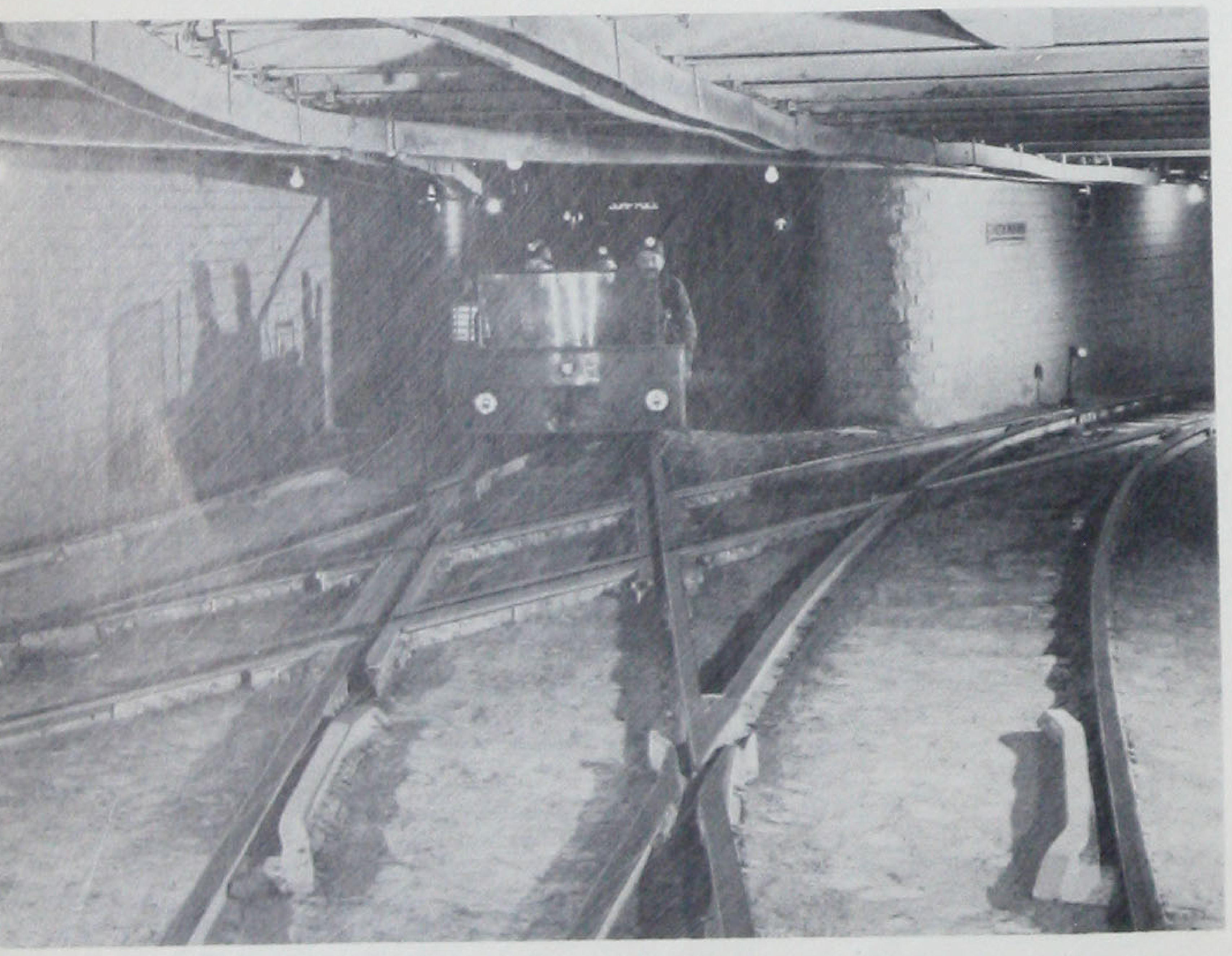
Large quantities of heavy rails are produced for railroads. Lighter rails are made for haulage systems in mines and industrial plants. Besides producing rails, Bethlehem fabricates track layouts, including curves, crossings and switches.

Rails Are Rolled from Blooms

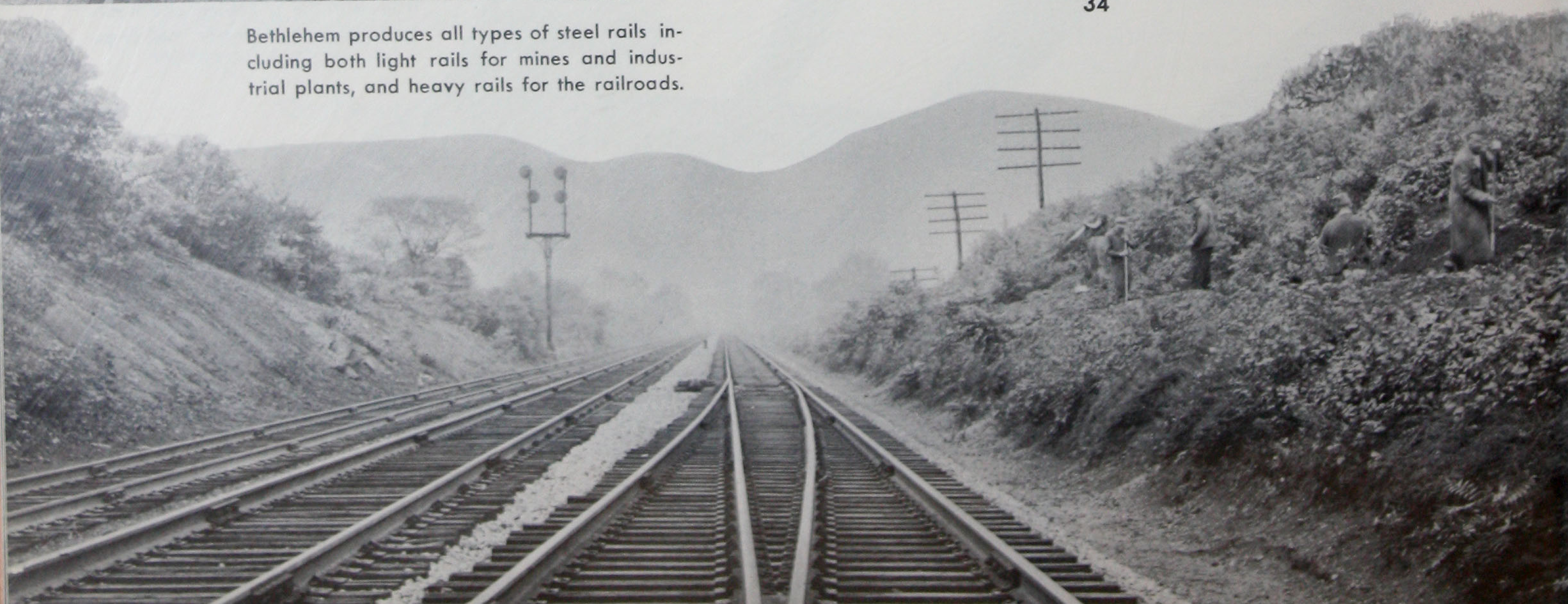
A roughing mill reduces and forms the reheated bloom into the approximate size and shape of a rail. Then, passing through a number of finishing stands, the steel is formed into T-shaped rails, sometimes as long as 120 feet, which are hot-sawed to standard 33- or 39-foot lengths.

After cooling to some extent on the mill hot beds, the heavier rails used in main-line service are placed in long covered metal boxes for *controlled-cooling*, a process developed by Bethlehem. This process eliminates dangerous transverse fissures or "shatter cracks" which might otherwise form during cooling. Another Bethlehem development is *end-hardening*, a method of heat-treating which hardens the ends of rails so they can withstand wheel battering at rail joints.

In order to provide rails that can better stand up under the severest conditions of modern railroading, Bethlehem has introduced heat-treated rails and trackwork. Heat-treatment, which includes oil-quenching and tempering, improves the physical properties of rails for use at points of unusual stress.



Bethlehem produces all types of steel rails including both light rails for mines and industrial plants, and heavy rails for the railroads.



BETHLEHEM PRODUCTS

STANDARD STEEL PLANT PRODUCTS

Pig Iron Blooms, Billets and Slabs Wire Rod

Plates Rails Structural Shapes Pipe Wire

Bars Special Rolled Sections Concrete Reinforcing Bars

Carbon, Alloy and Special Steels Ferro-Manganese

Tool Steels Coal Chemicals Steel Piling

Sheets and Strip Tin Mill Products

SHIPS OF ANY SIZE OR TYPE

SHIP REPAIRS

SHIP MACHINERY AND EQUIPMENT

MANUFACTURED PRODUCTS

Bridges, Buildings and Other Structures of All Kinds

Steel Freight and Mine Cars

Wrought Steel Wheels and Axles for Railway Equipment

Rolls—Steel and Cast Iron Flanged and Dished Heads

Nails, Staples, Barbed Wire and Bale Ties

Open-Web Joists and other Construction Specialties

Forgings Trackwork and Trackwork Accessories Tools

Bolts, Nuts, Rivets, Spikes and other Fasteners Gear Blanks

Wire Rope and Strand Hydraulic and Special Machinery

Guard Rails, Posts and Highway Specialties

Farm Fence and Posts Castings—Steel, Iron, Brass and Bronze

Oil Well and Refinery Equipment Tanks and other Weldments

INSIDE COVER

Wide-flange beams awaiting shipment at the Bethlehem Fabricating Works. Holes have been punched in the beams so that they can be quickly erected at the building site.

Lobby of Bethlehem Steel Company's general office building at Bethlehem, Pennsylvania. Reception desk is shown at the head of the stairway with elevators in background and waiting alcoves along either side.

BETHLEHEM

Steel and/or Manufacturing Plants

Bethlehem, Pa.	Seattle, Wash.
Corsicana, Tex.	So. San Francisco, Calif.
Johnstown, Pa.	Sparrows Point, Md.
Lackawanna, N. Y.	Steelton, Pa.
Lebanon, Pa.	Tulsa, Okla.
Los Angeles, Calif.	Williamsport, Pa.

Fabricating Works

Alameda, Calif.	Los Angeles, Calif.
Bethlehem, Pa.	Pottstown, Pa.
Buffalo, N. Y.	Rankin, Pa.
Chicago, Ill.	So. San Francisco, Calif.
Leetsdale, Pa.	Steelton, Pa.
Seattle, Wash.	

Shipbuilding and Ship Repair Yards

Baltimore, Md.	Quincy, Mass.
Beaumont, Tex.	San Francisco, Calif.
Boston, Mass.	San Pedro, Calif.
Brooklyn, N. Y.	Sparrows Point, Md.
Hoboken, N. J.	Staten Island, N. Y.

BETHLEHEM STEEL

BETHLEHEM STEEL COMPANY

General Offices: Bethlehem, Pa.

BETHLEHEM PACIFIC COAST STEEL CORPORATION

General Offices: San Francisco

Booklet 363

547, Printed in U.S.A.

BACK COVER

Lifting a glowing ingot from a soaking pit at the Johnstown Plant. The ingot is now ready for rolling.

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